Particulate Matter Research Program
Multi-year Plan
2003

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Not Yet Externally Peer Reviewed

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Office of Research and Development
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The Office of Research and Development's (ORD) multi-year plans (MYPs) present ORD's proposed research (assuming constant funding) in a variety of areas over the next 5-8 years. The MYPs serve three principal purposes: to describe where our research programs are going, to present the significant outputs of the research, and to communicate our research plans within ORD and with others. Multi-year planning permits ORD to consider the strategic directions of the Agency and how research can evolve to best contribute to the Agency's mission of protecting human health and the environment.

MYPs are considered to be "living documents." ORD intends to update the MYPs on a regular basis to reflect the current state of the science, resource availability, and Agency priorities. ORD will update or modify future performance information contained within this planning document as needed. These documents will also be submitted for external peer review.

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Introduction

Air pollution from anthropogenic activities continues to adversely impact human and ecological health in the United States, as repeatedly demonstrated in scientific studies. These impacts are substantial, as indicated by an estimate that current air pollution regulations may result in annual reductions of tens of thousands of premature deaths and prevention of hundreds of thousands of hospitalizations, representing monetary benefits of possibly hundreds of billions of dollars each year. The goal of the U.S. Environmental Protection Agency's (EPA's) air quality program, to "protect and improve the air so it is healthy to breathe and free of levels of pollutants that harm human health or the environment," thus represents a target for achieving major benefits on personal, national, and economic scales. In order to move the nation closer to achieving this goal, EPA concluded in 1997 that ambient levels of particulate matter (PM) presented significant risks to public health, based upon an extensive review of the scientific literature. The Agency therefore established revised National Ambient Air Quality Standards (NAAQS) for PM_{10}; in addition, new NAAQS were established for $PM_{2.5}$. At the time the new and revised PM NAAQS were established in 1997, President Clinton stated "The EPA, in partnership with other Federal agencies, will develop a greatly expanded coordinated interagency PM research program. The program will contribute to expanding the science associated with particulate matter health effects, as well as developing improved monitoring methods and cost effective mitigation strategies."

To effectively implement this and other research programs, EPA's Office of Research and Development (ORD) is relying on multiyear plans (MYPs) as one of the tools applied to identify research directions, opportunities for collaboration and integration across the different parts of the organization and different areas of research, and to communicate ORD's research programs within and outside the Agency. The PM MYP serves to link the broader EPA and ORD Strategic Plans with the more focused PM Research Strategy and research plans specific to ORD's three Laboratories and two Centers, as well as to other ORD research programs. A clear MYP will also provide the foundation for ORD and EPA to maintain their leadership positions in air quality research and management. A well defined research "road map" is necessary to ensuring that ORD's PM Research Program is able to build upon the progress that ORD has made over the past five years of the Program, and to effectively adjust to unforeseen changes in the complex scientific landscape ahead.

Developing this roadmap requires identifying a logical progression of scientific research. This progression is defined using the logic diagram shown in Figure 1. Each of the projects conducted in ORD's PM Research Program is designed to improve the Agency's ability to achieve its desired long-term outcome of improved human and ecosystem health. By following the logic diagram from right to left, one can begin to see how each research project contributes to the achievement of the long-term outcome. In a broad sense, the model in Figure 1 illustrates how the Program is guided by the need to provide the scientific foundation to enable the end users of our research (i.e., our customers) to set and attain air quality standards for PM that will protect human and ecosystem health.

In addition to guiding the PM Research Program, the MYP also identifies links to other ORD research programs. Research being conducted under the PM Research Program will also be applied to ORD's research efforts in ozone, air toxics, and climate change. Data for emission inventory improvement, better understanding of atmospheric processes, development of air quality models, characterizing actual human exposures and the factors which influence these exposures, effects of PM components on the rate of climate change, health effects caused by exposure to multiple pollutants, and evaluations of changes in control technology performance as different systems are installed are key areas where ORD PM research crosses programmatic definitions (more detail on these cross-program impacts is provided in Appendix A).

The ORD PM Research Program is fundamentally problem driven: "How can we reduce health risks associated with exposure to ambient PM?", derived from the Agency's desired long-term outcome to improve human and ecosystem health. The program's long term goals (LTGs) reflect the problem-driven nature of the program by defining research results that are needed to answer this key question and the more detailed scientific questions that logically flow from it. However, the ability to adequately answer this question requires that ORD rely upon and further develop its core research capabilities. The research conducted in a diverse range of topics such as cellular toxicology, atmospheric chemistry, human exposure, and combustion technology will not only address research questions of immediate interest to reducing PM-associated health risks, but will also provide a solid foundation for addressing the scientific questions that must be addressed to solve future environmental problems. As is true for any leading scientific research organization, it is a fundamental requirement that ORD scientists continue their contributions to advances in the state of the science. For ORD, the difference is that these advances are in directions designed to further the Agency's mission, and the MYP is a key tool for identifying those directions.

The scope of this MYP is the research conducted at and funded through ORD's three Laboratories (the National Exposure Research Laboratory [NERL], the National Health and Environmental Effects Research Laboratory [NHEERL], and the National Risk Management Research Laboratory [NRMRL]) and two of its Centers (the National Center for Environmental Assessment [NCEA] and the National Center for Environmental Research [NCER]). These organizations are working together under a matrix-type management structure specific to PM to develop their individual PM research programs to address the needs of ORD's customers.

The primary customer for the work described in this MYP is the Office of Air and Radiation (OAR). In addition to OAR, ORD's research is also designed to address the needs of the Regions, states, tribes, and Regional Planning Organizations (RPOs) in their activities to reduce ambient concentrations of PM, PM exposures, and, ultimately, PM-related effects. ORD itself can also be considered a key client of the PM research program, since many of the program's outputs are used by others within ORD to achieve ORD's broader goals. In addition to supporting these customers, ORD's PM research also supports environmental protection efforts beyond the borders of the U.S. International organizations such as the World Health Organization rely upon ORD outputs and expertise to inform their activities and conclusions, and

ORD works with scientists and policy makers from numerous countries to promote the exchange of the latest scientific knowledge in support of policy development.

While OAR is the primary customer for the research described in this MYP, ORD must also be responsive to other groups. In particular, the National Research Council's Committee on Research Priorities for Airborne Particulate Matter, resulting from a Congressional directive, has identified priority research areas and provided ongoing guidance that together have strongly influenced the design of ORD's PM Research Program. The official role and the scientific expertise of the NRC Committee make it imperative for ORD to place strong emphasis on the Committee's recommendations in its program design. The recommendations from and interactions with the NRC and other external groups will be discussed in more detail below.

The research described in this MYP is based on an assumption that the total available resources will remain level. In Fiscal Year 2002 (FY02), a total of nearly $68 million dollars and 177 full-time equivalent personnel were allocated to the PM Research Program. Of the total dollar amount, $34 million was available to fund research and development activities other than personnel costs. Of this amount, just under $17 million was available for funding the intramural research programs, with the remaining funds available for extramural grants and centers. The proposed FY03 budget is similarly structured.

Background

The logic of the PM Research Program's design, illustrated in Figure 1, begins with the Agency's desired long-term outcome of improving human and ecosystem health through achievement of EPA's **Goal 1 - Clean Air: Protect and improve the air so it is healthy to breathe and free of levels of pollutants that harm human health or the environment.** Achieving this outcome will benefit tens of thousands of people across the U.S., by reducing the frequence and severity of respiratory and cardiovascular symptoms and hospitalizations, preventing premature deaths, and possibly reducing the number of cases of lung cancer. Reducing concentrations of PM in the ambient air may also reduce cases and severity of asthma. In addition to these benefits to human health, reduction of ambient PM concentrations will improve visibility in both rural and urban areas, providing additional benefits to quality of life. On a dollar basis, these reductions in ambient PM have been estimated to be worth tens of billions of dollars each year. To achieve this outcome and its associated benefits, the Agency's near-term desired outcome is to develop and implement air quality standards that are protective of health and welfare as set forth in the Clean Air Act. These standards are set based on a comprehensive scientific understanding of the exposures to, and adverse health and environmental effects associated with (in this case), elevated levels of ambient PM concentrations, and are implemented by the states and tribes using tools and data provided in large part by EPA. As seen in Figure 1, setting and implementing PM standards represents the Agency's desired short-term outcome, which is designed to lead to the intermediate outcome of attaining those standards across the country as a means of ensuring individuals are able to breathe clean, healthy air. The efforts to develop, set, and implement these standards are made by organizations other than ORD, primarily the states, tribes, and OAR.

Because of the time required to set and implement national standards, significant time may elapse between the time ORD transfers knowledge to our customers and the time that knowledge is applied.

The objective of ORD's PM research program is then to transfer the scientific understanding, technical tools, and associated data to OAR, the states, tribes, and other clients to improve their ability to achieve first the short-term outcome of setting and implementing standards, and ultimately the intermediate- and long-term outcomes of ensuring safe and healthy air and improved human and ecosystem health. To meet this objective, ORD must go beyond a mere transmittal of data. An effective transfer of tools or knowledge requires substantial efforts to ensure that those receiving the information do in fact understand, for instance, the implications of using data in a context different from that in which they were collected or how supplied tools work and can be applied and modified. Areas where the effectiveness of transfer can be improved will be discussed in more detail below.

The key question stated earlier, "How can we reduce health risks associated with exposure to ambient PM?," incorporates the Agency's desired long-term outcome (improved health) and its short-term outcome (develop and implement standards). Answering this question implies a well-developed understanding of how health risks are related to ambient PM levels, and more explicitly indicates that the Agency's goal is to reduce the causes of the problem through its statutory authority. This question provides the starting point for developing the ORD research program, and from it flow the more detailed questions that can be answered through ORD and other research efforts.

Given unlimited resources, every aspect of the issue could be addressed. However, ORD (like any other organization) has neither unlimited time, funding, nor people at its disposal. Thus, ORD must focus on the critical research questions that will provide EPA with the scientific information and tools needed to achieve its desired outcomes, on a schedule that meets the needs of OAR's legally mandated timeline (see Figure 2). Narrowing the range of research topics to those questions of greatest importance has been accomplished through several means. Guidance from outside organizations to provide a scientific consensus on the key science questions, input from ORD's clients concerning needs to achieve desired regulatory outcomes, awareness of research efforts outside the Agency, and understanding the unique role and capabilities of ORD provided the means to narrow the research to that which is most critical to achieving the desired ORD and Agency outcomes.

Identifying Key Science Questions

In 1997, Congress requested that the NRC review the ORD PM research program. The NRC's Committee on Research Priorities for Airborne Particulate Matter undertook this effort with the objective of reducing "uncertainties in the scientific evidence used to guide regulation of airborne particulate matter in the United States." In their first report in 1998, the Committee recommended to the Agency a comprehensive research portfolio designed to identify the

biologically active constituents of PM that caused the associations between elevated levels of ambient fine PM and measures of adverse health effects, including premature mortality. Their first report identified ten key research priorities, chosen based on their scientific value, their decision-making value, and their feasibility and timing. The Committee has since published two additional reports on their findings, and have adjusted the ten priority research areas to reflect scientific progress and a more complete understanding of ORD's role in supporting the setting of PM NAAQS and the implementation of those standards.

The priority research areas identified by the NRC Committee focused on understanding:
1) how people were exposed to ambient PM mass and how these exposures related to concentrations measured at central monitors;
2) how people were exposed to toxic PM constituents and how those exposures related to constituent concentrations at central monitors;
3) what sources were emitting PM most strongly associated with the adverse health effects;
4) how PM emissions were related to ambient concentrations;
5) what characteristics of PM were causing the adverse health effects indicated in epidemiological studies;
6) how exposure to ambient PM is related to actual dose and how particles deposit in the body;
7) how PM interacted with other pollutants to cause adverse effects;
8) what groups in the total population were most susceptible to these effects;
9) how the effects occurred in the body; and
10) how measurement uncertainties can impact the epidemiological studies upon which the NAAQS are largely based.

More recently, the draft NARSTO[1] Fine Particle Assessment has listed eight policy questions and associated science questions focusing more closely on implementation-related issues. These questions were developed following extensive discussions with leaders in industrial, governmental, and academic institutions in the U.S., Canada, and Mexico, and further provide guidance to ORD concerning priorities for PM research. Additional guidance has also come out of ORD's leadership role in the Council on the Environment and Natural Resources (CENR) Subcommittee on PM Research. This group coordinates the PM research activities across 19 Federal agencies to ensure that priority needs are being met without duplicating efforts, and collaborative research opportunities are identified and taken.

The NARSTO Assessment provided more detailed questions related to implementing the NAAQS, emphasizing the need to reduce uncertainties in the relationships between source

[1]Formerly an acronym for the North American Strategy for Tropospheric Ozone, the term NARSTO has become simply a wordmark signifying this tri-national, public-private partnership for dealing with multiple features of tropospheric pollution, including ozone and suspended particulate matter.

emissions and ambient PM concentrations and approaches to reduce them. The Assessment also poses a critical question not explicitly addressed by the NRC: "How can we measure our progress?" The basic idea behind this question is also raised by the CENR's PM Subcommittee. In both cases, the key idea is to ensure that we are able to measure our progress toward meeting the broader Agency goals of safe and healthy air and improved human and ecosystem health.

Guidance from Primary Clients

In addition to the scientific guidance provided by these three groups, ORD's PM research program is also guided by the scientific needs of OAR, the Regions, the states, tribes, and the Regional Planning Organizations (RPOs) in their efforts to develop effective regulatory programs. The NAAQS timeline, including the development of the PM AQCD, is the primary driver of the research program's schedule. Other OAR regulatory activities supported by the ORD PM research program include the recent PM transport rule, the regional haze regulations, and mobile source emission standards. These programs rely on the ORD PM research program to provide data from health, exposure, atmospheric, and engineering sciences to ensure that regulatory programs are based on strong scientific evidence and analyses and have the greatest potential to achieving the Agency's desired outcomes. Not only are these data used by OAR, but also by the states and tribes, who have the primary role in implementing the NAAQS, and the Regions and RPOs in their roles as coordinating efforts across states to develop effective regulatory programs.

Research Outside the Agency

There is considerable PM-related research being conducted outside the Agency. Health research, including epidemiological, toxicological, and clinical studies, is being conducted in Europe by several organizations. In the U.S., epidemiological studies are being supported by industrial organizations including the Electric Power Research Institute (EPRI), and the Coordinating Research Council (CRC) through their support (co-funded by EPA) of the Health Effects Institute. Recently, ORD, the National Institute of Environmental Health Sciences, and the National Heart, Lung, and Blood Institute co-sponsored a workshop on the cardiovascular effects of environmental pollutants. Planning is underway to develop joint RFAs in the area of cardiovascular effects of PM exposure.

Several groups are also conducting air quality studies, including ambient PM measurements by the Department of Energy (DOE) in the upper Ohio River Valley and multi-agency state efforts in California and Texas. Multi-state organizations such as Northeast States Coordinated Air Use Management (NESCAUM) and Regional Planning Organizations (RPOs) in the Midwest are also sponsoring studies of ambient air quality. In conjunction with its epidemiological studies, EPRI is conducting air quality studies in the Southeast under its Southeast Aerosol Research and Characterization (SEARCH) study.

In emission characterization and inventory development, the Department of Agriculture (USDA) is providing support for research to improve emission inventories for ammonia from agricultural

operations. There are also several projects related to emission inventory improvement and air quality model application being conducted by states and the RPOs. Further emission inventory and characterization work is being conducted or supported by EPRI, the American Petroleum Institute and Gas Technology Institute, and the CRC.

As noted earlier, EPA stays abreast of this work (both health and implementation research) via its formal participation in the CENR and NARSTO, as well as through scientific and technical conferences and organizations. Information on these complementary research activities is taken into account by both Principal Investigators and ORD scientific and technical management when research needs are developed to meet the goals of the MYP. Whenever possible, EPA and ORD work together with other organizations at the Federal, state, tribal, and local levels to leverage resources and enhance our abilities to achieve EPA's desired long-term outcomes.

ORD's Unique Role and Capabilities

ORD has a unique position in the research community. Not only do outside researchers look to ORD, as a part of EPA, for guidance concerning the relative importance of topics, but ORD must also be able to judge the quality of research results produced by others and provide expert guidance on this research to EPA's regulatory programs. Therefore, ORD must conduct work that goes beyond merely filling in the gaps and addressing deficiencies in the science. By conducting a part of its research on topics that are also being evaluated elsewhere, ORD scientists play their part in the scientific community to independently verify others' research, and to provide a source of expertise within the Agency that would not be available without first hand experience.

This unique position of ORD within the broader research community also means that in many cases ORD has the role of scientific leadership on topics associated with PM. Certainly it is not expected that the leading researchers in every topic are ORD staff members. But as an organization, ORD is looked to by nearly every group as having the responsibility for generating, synthesizing, and reporting to EPA's regulatory programs the information and knowledge required to develop and implement air quality standards that are effective, in terms of their ability to reduce exposure, improve health, and minimize the cost of implementation. This is true not just in the U.S. but globally, as demonstrated by the requested participation of ORD scientists in international panels on the range of science associated with PM. Beyond this synthesis, ORD provides the Agency with the scientific link to translate the fundamental research conducted largely at the nation's academic institutions into the applied science needed to develop the regulatory approaches and achieve the Agency's desired outcomes.

The extramural programs developed by NCER provide the capacity to bring additional expertise to bear upon the range of issues associated with PM. Working jointly with the ORD laboratories and OAR, NCER develops requests for assistance (RFAs) to address specific research priorities that target key research gaps and deficiencies and create an mix of internal and external efforts that are at least complementary and optimally synergistic. A prime example of this are the five

competitively-selected PM Centers that are conducting health effects, exposure and epidemiology research, each aimed at a specific health hypothesis. In addition, the 50 individual grants provided through NCER also provide a means to support studies of new ideas and more focused investigations of topics important to gaining a better understanding of PM and its effects.

Internally, ORD is conducting leading-edge research that is advancing the state of the science in several areas. These areas include integrated epidemiological, clinical and toxicological investigations of the effects of PM exposure, development of ambient PM monitoring methods and air quality models used for compliance purposes, identifying the sources and factors influencing actual human exposures, and measuring particle size distribution and size-segregated composition of difficult-to-measure sources such as open burning. One of ORD's most significant advantages, however, lies in the close proximity of its exposure, health, atmospheric science, and engineering researchers. ORD's abilities to operate full- and pilot-scale combustion systems to generate particles in real time for inhalation toxicology studies and its capabilities in human clinical studies and developing and investigating animal models of susceptibility, for instance, provide EPA with the capacity to conduct top rank science in support of its regulatory programs. In each of these areas, ORD's research is seen as leading edge, and researchers throughout the world express interest in the results and directions of this work, and call upon ORD researchers to provide guidance to their programs.

Focusing ORD's Research

Based on the guidance provided by an understanding of the key science questions, regulatory program needs, efforts being made by others, and the unique capabilities and role of ORD, the PM research program can be narrowed from the broad key question above (How can we reduce health risks associated with exposure to ambient PM?) to a series of broad long term goals (LTGs) and more detailed annual performance goals (APGs) that are designed to increase our understanding of how human activities that emit PM and PM precursors are linked to adverse health effects, through the complex chain of emission, formation, transport, exposure, dose, and effect. The highest value research is that which addresses gaps and deficiencies in this chain. Constant review of these gaps through continuing interaction with the external research groups noted above will ensure that ORD's research maintains its high value. Continuing review of the research program to address the needs of the regulatory community will ensure that the ORD PM research program remains relevant.

ORD's scientific expertise, developed over years of studying the sources, behavior, and effects of pollutants in the atmosphere, and its understanding of the Agency's regulatory needs have enabled the NRC's priorities and other needs identified by OAR (and through OAR, the states and tribes) and NARSTO to be translated into the detailed project-level activities needed to answer the key question posed above. The PM Research Program was therefore developed from the scientific community's understanding of the gaps and deficiencies in scientific knowledge regarding PM source, atmospheric behavior and fate, human exposure, and ultimate health effects, within the framework of the Agency's regulatory mission. Close interactions with

OAR's Office of Air Quality Planning and Standards (OAQPS) and Office of Transportation Air Quality (OTAQ), ensure that the information generated by ORD addresses the needs of these Offices as they develop, implement, and enforce the rules, regulations, and standards designed to achieve the Agency's strategic goal of clear, safe, and healthy air in every American community.

Progress to Date/Changes from Previous Version

Progress to Date

The program has steadily progressed toward meeting its goals since the previous revision of the MYP. The most visible product generated by the program has been the most recent revision and review of the PM AQCD. Due to an unprecedented volume of new research, as well as a recently-discovered issue regarding statistical models used in some epidemiology studies, completion of the AQCD has been delayed beyond the original target date. However, ORD has worked closely with the scientific community and OAR to set a revised schedule for completing the final draft, review, and publication of the AQCD.

ORD has made substantial progress in addressing the research priorities established by the NRC in response to 1997 revision of the PM NAAQS. The new standards were developed largely on the basis of epidemiological studies that found consistent associations between ambient PM concentrations and various adverse health effects. However, these studies raised two important questions: whether PM at ambient levels could actually cause these health outcomes, and whether ambient monitors could be used to adequately represent personal exposure to PM mass. Research conducted and supported by ORD has since developed a body of evidence demonstrating that the adverse health effects statistically associated with exposure to ambient PM are biologically plausible. That is, studies of controlled exposure to measured concentrations of particles from different sources and with different attributes can cause measurable changes in biological response, consistent with the health measures used in the epidemiological studies. This research has also demonstrated that for fine PM mass, differences between ambient measurements and exposure should not change the predicted health outcomes, although the difference may underestimate the strength of the impact. Although significant questions remain regarding how and what PM components and factors of susceptibility result in PM health effects, these achievements provide strong verification of the fundamental epidemiological evidence which was the basis for the 1997 revision of the PM NAAQS.

The initial ORD grants supporting the PM Health Centers are coming to a close in 2005, with this support having already resulted in numerous publications describing the effects associated with exposure to particles with different characteristics and from different sources, thereby expanding our understanding of which particle components or characteristics may be causing adverse health effects. The Supersites monitoring network is completing or is near completion of the data collection portion of the studies, and the data are being made available to the scientific community for analyses. The PM Exposure Panel Studies have been completed, with much of the data analyzed, and the Stochastic Human Exposure and Dose Simulation (SHEDS) model was applied to better understand exposure to fine particles. An updated version of the

Community Multiscale Air Quality (CMAQ) dispersion model was released for public use to analyze the impacts of potential implementation strategies by the states, tribes, and RPOs.

The work that has been conducted to date and the progress that has resulted from that research have not only provided significant guidance to our customers concerning sources, transport, transformation, deposition, exposure, and effects of PM, PM precursors, and PM components, this research has also positioned ORD scientists and the external scientists supported by ORD in a position to make further significant advances in the state of the science in the coming years. As with any scientific endeavor, considerable time and effort was expended during the initial period of research to develop methods, set up facilities, and generally learn the intricacies of the different fields of investigation. We have now gotten the ball rolling and are beginning to see the first fruits of our efforts. The future should provide increasingly more answers as the research progresses.

Changes in MYP Direction

Scientific progress over the past several years has led to several changes in the program's direction. The incremental nature of research means that these changes will in most cases appear at first glance to be minor adjustments in the descriptions of ORD's PM research. However, these seemingly minor adjustments can over a long term represent significant changes in scientific direction.

The most important of these changes over the past five years has been in the effort to determine the PM characteristic(s) responsible for causing the adverse health effects associated with exposure to ambient PM. In the NRC's first report on PM research priorities, emphasis was placed on research to identify "the most biologically important physical and chemical characteristics and constituents of particulate matter that produce adverse health effects." The NRC's original ten research priorities were designed to identify the specific constituents or characteristics causing the adverse health effects (the "silver bullets"), the biological mechanisms of damage, who and what make certain subpopulations susceptible, and how people are exposed to these harmful particles. The goal behind the determination of which particle attributes are most toxic was to identify and ultimately reduce emissions from the sources of those biologically important particles.

While the need to understand the roles of physical and chemical characteristics and constituents remains a key to more fully understanding PM-associated health effects, these efforts are now being integrated to better understand the impacts of particles from specific sources. The subtle extension of emphasis from characteristics and constituents to sources reflects the growing consensus that the search for the "silver bullets" is likely to be a long-term continuing effort. Linking specific sources through ambient concentrations and human exposures to health effects is likely to provide data that can be applied to regulatory policy more quickly, and can help support identification of biologically important characteristics and constituents as well. Source-exposure-effects approaches take into account the complex nature of ambient PM, which is

mixed internally and externally to form particles with an enormous range of possible characteristics and constituents that would individually take a correspondingly enormous amount of time and effort to identify and evaluate.

NHEERL is conducting a number of studies designed to better understand the effects associated with particles from specific sources, using concentrated ambient particles (CAPs) or particles generated by pilot- and full-scale combustion equipment, including diesel engines. These particles are collected and then used in animal and human *in vitro*, *in vivo*, and clinical exposure studies to measure the biological responses following exposure. NCER is also funding work to improve understanding of the link between sources and effects, including support of an epidemiological study associated with EPRI's Aerosol Research Inhalation Epidemiology Study (ARIES) in Atlanta. Internally, NERL scientists are developing data and models to characterize and predict exposures to PM from different sources relative to that measured at ambient sites.

As increasing amounts of data on the speciation of ambient PM are generated by recently expanded monitoring networks, ORD will have greater opportunities to conduct source-related epidemiological studies. These studies will broaden and build upon the current toxicology-based research efforts to generate the most useful information possible on the impacts to human health of particles from specific source types. Even with the increasing emphasis on source-based effects, studies of specific PM components and characteristics must remain a key part of a robust health effects research program. These studies work in concert with source-based investigations to guide scientific progress toward understanding what factors influence personal exposure to PM, why that exposure to particles is harmful, what specific particles are harmful, and where these harmful particles originate, so that we can most effectively target for reduction those emissions, exposures, and, ultimately, effects.

A second instance in which research findings have resulted in changes in research program direction is in the area of emission characterization. Improvements to air quality models have significantly reduced the differences between predicted and measured ambient PM concentrations in validation runs using historical data. As these differences are reduced, errors in model inputs (such as emission inventories) have a greater impact on the modeled results than in previous versions of the models. Inverse modeling techniques suggested that a significant portion of the difference in modeled vs. measured particulate nitrate concentrations was due to overestimates of ammonia emission rates. In response, increased efforts to quantify ammonia emission rates and to understand the role of ammonia deposition between point of emission and the well-mixed atmosphere are being made to address this issue.

The most significant programmatic change that has impacted the MYP is a shift of resources from health and exposure research to implementation research. This shift has occurred in both the extramural and intramural portions of the program. The reason for this shift was to address the immediate need to provide improve data and tools to implement the current fine particle NAAQS. This work will focus on near-term priority OAR needs. The initial research

conducted under this shift will be further development of the CMAQ model and improvements to ammonia inventories, followed by more rapid development of source signatures receptor models, source apportionment results, and atmospheric chemistry modules. This shift, in combination with general budget reductions, will result in the elimination of in-house chronic epidemiological studies and animal studies of long-term health effects of PM exposure. Support for chronic epidemiological work will continue through NCER grants, which may also provide an opportunity to support extramural animal studies of chronic effects. Delayed work includes evaluation of the health effects of specific PM components in new animal models of susceptibility, and studies of PM exposure. The changes to the intramural chronic effects research does not impact the program's strategic directions or its abilities to achieve its long term goals. It is anticipated that resources will shift back toward health and exposure work as the regulatory cycle moves closer toward the next review of the NAAQS in 2009-10.

The most visible change from the previous version of the MYP is the change in LTGs. The LTGs have been recast to reflect a more outcome-oriented description of the program rather than a more detailed description of the program activities and outputs. The previous LTG dedicated to susceptibility has been absorbed into the LTGs for health effects caused by long- and short-term PM exposures, and an LTG has been added that encompasses the synthesis, integration, and assessment activities associated with developing the PM AQCD and PM Research Needs documents.

Overview of the Long Term Goals

The PM Long Term Goals have changed substantially from the previous version of the PM MYP. These changes were made to better communicate the key desired outcomes of the research program and to provide the foundation for future planning toward meeting the broader Agency strategic goals. However, these changes do not reflect a substantial change in the direction of the program itself. The LTGs are designed to identify the outcomes needed to meet the Agency's goal to improve public health through reduced personal exposure resulting from improvements in ambient air quality, and reflect the program's two basic tasks: to support the Agency in setting PM NAAQS that are protective of public health, and to provide the data and tools needed by the Agency and states and tribes to attain the PM NAAQS. Figure 3 illustrates how the LTGs relate to each other and to the regulatory programs in the overall strategy to achieve EPA's desired long-term outcomes. The LTGs provide the framework around which the program is designed, with more detailed and measurable outcomes being defined by the Annual Performance Goals (APGs). The PM LTGs are:

1. Implementation of the Fine Particle NAAQS: By 2006, develop and transfer new data and tools needed by OAR and the states and tribes to predict, measure, and reduce ambient PM and PM emissions to attain the existing PM NAAQS.

2. Effects of Short-Term Exposures to PM: By 2009, develop and transfer to ORD and OAR new exposure, epidemiological, toxicological, and clinical data for improved

assessments of health risks associated with short-term exposure to PM in the general and select susceptible populations.

3. Air Quality Criteria Document: By 2010, integrate and assess new findings in atmospheric, exposure, biological, and environmental sciences and regularly communicate the state of science to OAR to improve environmental decision-making for the PM NAAQS.

4. Implementation to Address Residual Non-Attainment: By 2012, develop and transfer improved data and tools needed by OAR and the states and tribes to attain the PM NAAQS, especially in areas that remain in nonattainment after initial control strategies are implemented, and by ORD and other scientists to refine the environmental factors related to health risks associated with PM exposure.

5. Effects of Long-Term Exposure to PM: By 2014, develop and transfer to ORD and OAR new exposure, epidemiological, toxicological, and clinical data for improved assessments of health risks associated with short- and long-term exposure to PM, especially in susceptible populations.

In general, the timeline for the NAAQS is to identify and quantify the health and environmental problem, set the Standard, identify areas that have not attained the NAAQS, and require the development of State Implementation Plans (SIPs). In short, the regulatory flow is health-exposure/standard-setting/ implementation, and the LTGs have been developed to support this flow. This is illustrated in Figure 3. The components of the NAAQS review, setting, and implementation are not shown in a linear manner because in practice, these efforts must be carried out in parallel in many cases. This is due to the time required to conduct the research and to the fact that this process is cyclical, with the review and revision (if needed) occurring every 5 years as mandated in the Clean Air Act.

Following the process sequentially (denoted by the bold arrows in Figure 3), improved understanding of exposure and effects (covered in the 2009 and 2014 LTGs) allows ORD to develop more accurate risk assessments, which in turn allows OAR to develop more effective air quality standards. Better modeling and measurement tools and more accurate inventory data (developed under the 2006 and 2012 LTGs) provide the basis for more effective implementation of the standards by OAR, the states, tribes, and other governmental organizations, and the regulated community. Effective implementation of protective standards results in reduced exposure to PM and to ultimately improved human and ecosystem health.

The arrows between each box in Figure 3 represent information and/or technology transfer. For the above process to flow smoothly, ORD must not only conduct the correct science, but must also make sure that our key customers understand our results and the implications of those results. We must also ensure that the different parts of ORD understand the implications of research conducted by others, both internal and external to ORD.

The **2006 LTG** is focused on research needed to improve implementation of the existing PM NAAQS. By achieving this goal, ORD will provide OAR, the states and tribes, and the regulated community with tools and data to develop more effective implementation plans and control strategies. More accurate air quality models and source apportionment methods, data on ambient measurements and methods, emission rates and characteristics, and control technology performance and costs will **allow OAR and the states and tribes to develop and implement the current PM NAAQS more effectively**. That is, they will have a clearer understanding of what sources are contributing to ambient concentrations, how control strategies will reduce emissions and ambient PM levels, and how much those strategies are likely to cost. These improved data will help OAR and the states and tribes to achieve the greatest improvement in air quality at the least cost, progressing toward the ultimate goal of improved human and ecosystem health.

The **2009 LTG** covers research to expand our understanding of exposure to and health effects caused by PM in support of the next NAAQS review in 2010. The 2009 LTG focuses on exposure and health effects associated with short-term exposure to ambient PM. This work is designed to increase our understanding of what types of particles are most toxic, how people are exposed to these particles, who is susceptible, and how these particles cause the adverse health responses. Achievement of this goal will result in more detailed information on what attributes of particles are considered to be most responsible for the adverse health effects associated with PM exposure in the epidemiological studies, and who is most likely to be affected. This information, in turn, will **enable the development of a risk assessment that includes stronger information on the links between particle sources and effects**, which in turn will provide the foundation for determining whether the PM NAAQS needs to be revised, and if so, in what respects.

The **2010 LTG** reflects the efforts to collect and integrate the appropriate information on ambient PM concentrations, exposures, and effects, and report that information to the public and to the Administrator so that a determination can be made concerning whether the NAAQS is adequately protective. In contrast to the 2009 LTG, which focuses on the development of exposure and effects data, this LTG is focused on the collection, integration, and reporting of those results and the results reported by others. In short, the information collected, summarized, and reported under this LTG will **give the regulatory decision makers more complete information upon which to base their decisions concerning whether public health is being adequately protected by the existing NAAQS**, or if revisions to the standard are warranted by the data, how the form or level of the standard should change.

The **2012 LTG** focuses again on implementation-related activities, reflecting the cyclical nature of the NAAQS process. In this case, however, the focus of the research is designed to address residual nonattainment areas that are expected to remain after the implementation of regulatory measures to reduce ambient sulfate and nitrate concentrations. Under the 2012 LTG, work will focus on attainment of existing PM mass standards, identifying sources of the ambient

carbonaceous particles that are expected to be the most pressing problem in the future, improving our understanding of how changes in emissions have altered the atmospheric chemistry, and improving the capability to control emissions of multiple pollutants in a cost-effective manner. By achieving this LTG, ORD's research will provide OAR and the states and tribes with better monitoring methods and models, better information on what sources impact air quality, including intercontinental air pollutant transport, more accurate emission inventories, and up to date information on the performance of pollution controls. These improved tools and data will **enable OAR and the states and tribes to more accurately link sources to ambient concentrations and to design more targeted control strategies** to reduce emissions and ambient concentrations, ultimately resulting in cleaner air.

In addition, these more accurate data and predictions will also provide a foundation for future health studies by generating speciated information on ambient PM concentrations, and mass concentration data over time periods shorter than 24 hours. To the extent ambient monitors adequately represent personal exposures to PM components, these more detailed air quality data can then be used in epidemiological studies to evaluate both the effectiveness of control strategies applied to date, as well as health effects associated with specific particle types over shorter exposure periods. These efforts will require close coordination and integration between the health and exposure research and the implementation related research to address the increasingly complex task of understanding the causes of adverse health effects. This integration and the ensuring information are critical to allowing future PM standards to take into account as many measures as possible to ensure that public health is adequately protected.

The **2014 LTG** is the last long term goal in this MYP. The research under this LTG is focused on exposure and health effects associated with long-term exposure to ambient PM, and a more complete evaluation of particulate matter components and susceptibility issues associated with short-term PM exposures. Long term exposure to PM has not been examined in as much detail as short term exposure. There may well be significant differences in toxic particle attributes, exposure patterns, biological mechanisms, and susceptibility compared to these same issues related to short term exposure, which (if the differences are substantial) could have significant impacts on the form and level of PM standards. Based on existing economic cost/benefit data, such changes could have enormous impacts on the benefits associated with PM reductions because of the impact of shortened lifespans in cost/benefit analyses. Achievement of this LTG will **provide ORD risk assessors with more complete information on how the exposure patterns and health effects associated with long term exposure differ from those associated with short term exposure**, which in turn will enable OAR to identify what changes, if any, are needed to make the PM NAAQS adequately protective.

Scientific interactions between the LTGs are continuous, and are in some cases difficult to specifically identify. For instance, the exposure and health effects research supporting the 2009 LTG is anticipated to provide better information linking adverse health effects to particles from specific sources. As it becomes available, this information will be incorporated into activities

under the 2012 LTG to ensure that emissions from the appropriate sources are well characterized and that the necessary modeling, monitoring, and measurement methods have been developed to allow OAR and the states and tribes to effectively target the sources of most concern. Likewise, improvements in ambient monitoring capability and in our understanding of how those more detailed data relate to personal exposure can form the basis for new health studies. The ability to monitor specific PM components or characteristics or to provide ambient PM concentration data on hourly instead of daily can provide the basis for improved health effects studies that link ambient PM concentrations to adverse health effects associated with exposure to PM.

Description of the Flow Diagrams

Each of the LTGs has a set of underlying APGs and APMs that, if met, are designed to achieve the LTG. In some cases, the research covered by the APGs and APMs can be conducted in parallel, but at some point the efforts must be integrated into a coherent picture that will ultimately improve our understanding of how emissions of PM, PM precursors, and copollutants are linked through human exposure to adverse health effects, and thus how we can reduce those health risks by reducing emissions in the most effective way.

Table 1. Evolving LTG Emphases

	2003-2004	2005-2008	2009-2011
2006 LTG	Increase	Decrease	NA
2009 LTG	Decrease	Increase	Decrease
2010 LTG	Level	Increase	Decrease
2012 LTG	Level	Level	Increase*
2014 LTG	Decrease	Increase	Increase

Note that changes denoted are averaged over the several years in each column and do not necessarily represent annual changes.

*Assumes a revision in the NAAQS and associated increased implemention-related needs

To accomplish this, we mesh the programmatic needs outlined in the regulatory timeline (shown in Figure 2), which drives the dates for transferring information to OAR and other customers with scientific research timelines, that may be driven differently by the pace of scientific advancement. As a mission-oriented organization, the approach taken in the program and described in this Plan has been to focus on the regulatory timeline to define the timing of achieving the LTGs, while maintaining the scientific critical path. Taking this dual approach allows ORD to provide OAR, the Regions, states, tribes, and other customers with tools and information needed to implement the standards that are in place, while continuing to advance our understanding of risk identification, assessment, and management in a scientifically sound manner. The critical paths identified in this plan are those that define the scientific paths that need to be taken to achieve out-year APGs, the individual LTGs, and ultimately the desired

short-term outcomes.

Figures 4-7 illustrate the overall flow of the PM Program. Long term goals are shown at the bottom of each figure, with the APGs associated with each LTG included in the flow diagram illustrating how research progresses toward achievement of the LTG. As noted above, there are multiple APMs associated with each APG, and in some cases multiple research activities associated with individual APMs. For the purposes of the MYP, only APGs and LTGs are shown here (except in the case of the 2010 LTG, which shows the APMs associated with each APG). There is also considerable interaction between activities associated with the different LTGs, but these are not illustrated so that the overall flow can be more clearly seen.

Research conducted under the 2006 LTG requires substantial interaction between the different research efforts that fall under this goal. The main thrusts of this implementation-related research are ambient monitoring, source measurements, air quality and receptor models, and control technology evaluation. Achieving this goal will require coordinating measurement and analysis methods for source and ambient samples and receptor modelers, as well as an understanding of the emission inventory data needs of air quality modelers. To most effectively meet the Agency's desired outcome of reducing health risks associated with exposure to PM, researchers developing methods for emission and ambient measurements must be aware of what specific PM characteristics are of most interest to health effects researchers. Conversely, advances in measurement techniques can provide more detailed information on PM characteristics that can influence health effects studies.

The critical path for meeting the 2006 LTG is to complete and deliver the CMAQ model and emissions data needed for SIP preparation and implementation. These are tools and data needed by states, tribes, and OAR to meet the regulatory schedule. The 2006 LTG is designed to provide data for OAR and the states and tribes during SIP preparation between 2005 and 2007. Although the completion date for this LTG is 2006, the bulk of the work (as defined by the APMs, shown in the table in Appendix B) will be completed by 2005 and available to the end users.

For the 2009 LTG, the ability to develop data for improved assessments of health risks will depend upon improving our understanding of: the relative toxicities of different PM characteristics (size, composition, etc.) in different physiological systems (pulmonary, cardiac, etc.), both in the presence and absence of copollutants, and in healthy and diseased populations; what portions of the population are most susceptible to health effects caused by PM exposure; and how these (and other people) are exposed to PM. Initially, research can proceed along largely parallel paths as basic information is gathered. As specific PM characteristics are identified or eliminated as being particularly active in biological systems, results from exposure and susceptibility studies can be incorporated to improve the applicability of the program to the standard setting process. Data from emissions measurements will be used to determine what PM characteristics are most prevalent, and monitoring data will be used to evaluate the relationships between ambient and personal exposures.

The critical paths identified for the 2009 and 2014 LTGs represent the scientific steps needed to address the questions reflected in the National Academy of Science recommendations. The timing of these LTGs are set to provide the latest health and exposure information possible to the NAAQS review process, rather than the achievement of specific scientific findings. The critical paths for these research areas illustrate the logical scientific progression necessary to achieve the more detailed APGs, which in turn support the regulatory program through a transfer of knowledge as outlined in the LTGs.

The critical path to meet the 2009 LTG is to determine the effects of exposure to elevated PM concentrations, begin identification of susceptibility factors and at the same time identify the PM attributes resulting in toxic responses following short-term exposure, and characterize the combined effects of PM and gaseous copollutants. The last two topics are focused on effects in healthy populations. To be able to link ambient PM to effects, especially in susceptible populations, exposure studies are also required. Studies to determine the critical factors governing exposure to specific PM constituents will be followed by characterization of such exposures, and finally by the development of a model to enable exposure estimates to be made for a wide range of situations. The work under the 2009 LTG is timed to provide data to the next revision of the PM AQCD, so that the most up to date information is available for regulatory decision makers to support their efforts to review and retain or revise the PM NAAQS during the next review cycle expected to occur in 2008. Although the completion date of the LTG is 2009, much of the work is scheduled to be completed in 2008 or earlier.

The 2010 LTG is most closely tied to the regulatory schedule, since preparation and review of the PM AQCD is a required step in the NAAQS review process. Because of the cyclical nature of the NAAQS process, the initial APG describes the development of the PM Research Needs document, which derives from the AQCD. The critical path for meeting the 2010 LTG is represented by the 2008 APG, to integrate the body of PM-related research in order to assess the state of the science and provide that information to OAR through the PM AQCD itself, and through regular discussions and consultations with OAR. The 2010 LTG is scheduled to fit the projected 2008 PM AQCD revision.

The 2012 LTG is focused on addressing implementation issues that are expected to exist after several years of implementing measures to meet the current NAAQS. The issues will be focused on addressing any residual non-attainment areas and providing implementation tools for potential revisions to the NAAQS. Improving the ability to measure and predict PM mass concentrations and to characterize and control PM sources will continue to be an issue in the future. For example, states have expressed the desire to use continuous mass ambient monitors to reduce the burden of collecting samples. These types of monitors could also provide more temporally refined estimates of PM concentrations for use health studies. There will also be a need to better understand the carbonaceous component of PM, which is expected to form the bulk of ambient PM after current regulatory strategies are implemented. Finally, as states and tribes refine their implementation plans, they will need a better understanding of the relationships between PM

sources, PM precursors, and PM components, so that they can develop more effective control strategies. The LTG also includes aspects of integration of health and exposure sciences with implementation research. To most effectively meet the Agency's desired outcome of reducing health risks associated with exposure to PM, researchers developing methods for emission and ambient measurements must be aware of what specific PM characteristics are of most interest to health effects and exposure researchers. Conversely, advances in measurement techniques can provide more detailed information on PM characteristics that can influence health effects and exposure studies.

Based on current understanding (i.e., with no change in the basis of the PM NAAQS), the critical path for achieving the 2012 LTG will be to provide the prediction, measurement, and control technology tools needed to reduce mass and the information on how changes in emissions (and therefore ambient concentrations) impact atmospheric PM formation and transport. The 2012 LTG is scheduled to provide data for any revision to the PM NAAQS that may occur following the 2008 NAAQS review cycle, and the work under this LTG will be in place by the time any implementation activities for a revised standard, if necessary, occur.

For the 2014 LTG, many of the activities will be similar to those described for the 2009 LTG, but the emphasis will be on long-term exposure and how susceptibility factors influence the health effects and biological mechanisms of short and long-term PM exposures. Because the health impacts caused by long-term exposure may be significantly different, and may be caused by different PM characteristics, this research effort requires a special emphasis. The critical path for the 2014 LTG includes the identification of possible toxic particle attributes, biological mechanisms, dose-response relationships for susceptible populations, understanding personal exposures in a long-term context, defining methodologies required to gain the maximum amount of information from diverse data sets, and putting all these components together to determine the health effects associated with long-term exposure to PM. The 2014 LTG is scheduled to fit into the 2nd NAAQS review cycle, which is projected to occur in 2013. Again, the bulk of work under the 2014 LTG will be completed by 2013 so that results will be available for the review of the state of the science and the subsequent risk assessment.

In summary, ORD's PM Research Program is designed to improve the Agency's capability to achieve its desired long term outcome of improved human health, through identification, assessment, and improved ability to manage risks associated with exposure to ambient PM. ORD will increase the capability of OAR to develop more effective and protective ambient air quality standards by improving the understanding of the source-transformation-exposure-effects chain for short- and long-term exposures to PM, especially for those people most susceptible to these adverse health effects. ORD will improve the capability of OAR, Regions, states, and tribes to implement these standards more effectively, through improved monitoring, air quality and source apportionment modeling, emission inventories, and control technologies.

Communication

Communication is a critical part of ORD's PM Research Program, and entails much more than publishing research results or transmitting data to key customers. Effective communication requires in-depth interactions with customers, including listening to their needs and following up to ensure that information is understood and tools are capable of fulfilling their designed tasks. ORD has taken several steps to improve their communications with their customers.

The NRC, in their second report, recommended the development and implementation of a formal management structure to ensure that research results on implementation topics were quickly transferred to end users in OAR and the states. ORD and OAR developed such a management structure and are now using it to support continuing interactions between science and policy managers and staff. ORD participation in semiannual meetings of state and local working groups on air quality and receptor modeling, ambient monitoring, and emission factors and inventories provide a further means of communicating with end users of ORD's PM research.

ORD is also moving toward improved communication with our customers through changes in the formulation of LTGs, APGs, and APMs. By stating LTGs and APGs in terms of desired outcomes that reflect the impacts of ORD research on the ability of our customers to make science-based decisions, the PM MYP is more explicitly incorporating the need to communicate results as part of the research effort. And beginning in 2005, the successful achievement of each APG will be marked by the publication of a document summarizing the research conducted under that goal and the implications of that research for policy decision makers.

In some cases, however, more extensive efforts may be needed to fully achieve the levels of communication necessary to ensure that ORD's research is as useful as possible in its objectives of moving the Agency closer to its desired outcomes. For instance, efforts associated with developing air quality models that are expected to be broadly applied by states and tribes will require significant participation by OAR as well as ORD, and will also need an on-going technical support effort that reaches beyond the traditional research and development work. Current communication efforts with the states and tribes are often conducted via OAR and their outreach efforts. While these channels are capable of making external groups aware of research efforts and results, they do not provide the ability for in-depth discussions of technical details that may be of interest to the end users. The research and technical transfer efforts described in this document reflect the *status quo*; proposed additional communication efforts are outlined in the following section.

Potential Additional Work

Accountability

The broadest unfunded research issue not covered by any other LTG is the issue of accountability. While reductions in the number of PM nonattainment areas and the population

living in those areas are certainly indications of improved environmental health, they do not directly address the measures that led to the revision of the standard in 1997 - increased morbidity and mortality associated with increases in ambient PM concentrations. Complete accountability requires that measurements be made to determine the degree to which the PM NAAQS have led to improved health, especially among the most susceptible populations. A proposed new LTG for this area is:

By 2016, measure and report on the improvement in public health due to the 1997 revision and subsequent implementation of the PM NAAQS.

The date for this LTG would be aligned with the regulatory timeline, providing time for the standard to be implemented, reductions in PM concentration to be measured, and studies of health effects to occur. Ideally, accountability efforts would be broader than for PM alone, although the level of effort required to achieve the PM NAAQS and the projected improvements in public health from its implementation are such that quantifying the air quality and health improvements directly attributable to the PM NAAQS is by itself a valid goal. Suggested APGs under this goal include:

APG 1 - Publication of periodic reports to document progress toward achieving the goal of improved health (2006, 2011, 2016)
APG 2 - Measure baseline health levels to which subsequent health measures will be compared (2007), and subsequent health levels during and after source reductions are taking place (2014)
APG 3 - Develop improved biomarkers and methods to quantify changing exposures to and health effects from ambient PM (2009)
APG 4 - Quantify and report actual and avoided costs of PM reductions (2010)
APG 5 - Determine changes in atmospheric chemistry resulting from PM NAAQS implementation, and how further source reductions will be related to further ambient reductions (2007, 2013)
APG 6 - Identify which source reductions have contributed most to ambient reductions, or which sources need to be reduced or further reduced to achieve compliance through use of source apportionment methods (2008, 2015)

The CENR Strategic Research Plan for Particulate Matter notes that an "overriding need" is the "development of a PM Accountability Design Plan" that would address the approaches needed to quantify changes and to draw scientifically defensible associations between changes in emissions, ambient concentrations, human exposure, and adverse health effects.

The remaining additional work is largely covered by the existing LTGs, but represents needs for additional resources to cover expected personnel loss, conduct the next research step, or accelerate existing work.

Accelerated Investigation of Source-Exposure-Effects Links

Current research to link sources through exposure to health effects can be accelerated considerably by taking advantage of several opportunities in an integrated approach. The PM Supersites data collection efforts are either completed or nearing completion, OAR's Speciation Trends Monitoring Network is beginning operation, the PM Centers are moving quickly toward recompetition, and ORD's in-house source-based toxicity studies have completed initial studies and are moving toward increasingly complex investigations. In addition to this, the results of the ARIES project and the Southern California Supersite/Center have highlighted interest in the types of information that may be possible through epidemiological studies that are designed from the beginning to examine the relationships linking source emissions and adverse health effects.

Although the ORD PM Research Program is currently conducting work to understand these links and identify the sources of particles that are most damaging to health, expanding and accelerating these efforts have the potential to provide important information in support of standard setting. The Program's current capacity to carry out these studies is limited, resulting in an extended schedule toward completion. An expanded effort would include:

- Use of monitoring methods developed and tested by the Supersites, as well as potential use of the expertise developed during the Supersites program, to collect detailed speciation data in carefully selected locations.
- Concurrent exposure studies of source-specific PM.
- Concurrent health measurements, including heart rate variability and lung function.
- Epidemiological studies in the same locations as the detailed monitoring studies to evaluate associations of source-specific PM concentrations with health metrics.
- Accelerated experimental studies of animal and human exposures to particles from well-characterized sources, including particle aging in atmospheric reaction chambers.
- Accelerated clinical and in vitro studies of concentrated ambient particles, including source apportionment to determine particle sources.

As increasing amounts of research are conducted to determine the effects of exposure to PM, the task of revising the PM AQCD to adequately report on the state of the science becomes more extensive. Additional staff is needed by NCEA to adequately review, synthesize, and document the increased amount of research being generated for the development of the AQCD and support to OAR's development of the Staff Paper and standard revisions.

Acceleration of PM Health Effects Research

Research, whether conducted at EPA or supported extramurally, has not progressed at the speed anticipated by the NRC in their initial report in 1998, due to the complexity of the issues. To accelerate the priority research on health effects caused by PM exposure, additional funding would expand ORD's efforts in the following research areas:

Determination of the health effects associated with long term PM exposure. Understanding the health effects of long term exposure to PM has been recognized as one of the greatest health

research needs. Current intramural funding in this area has enabled ORD to begin a small chronic effects program that is funding pilot studies to identify potential cohorts, appropriate geographical locations, and the appropriate exposure measurements and health end points that will be required. Additional resources would be used to increase our ability to address the NRC's recommended research in this area, specifically to develop, improve, and evaluate the biological significance of end points used to measure the health effects of long term exposure, to better characterize the health effects of long term exposure to PM in animals and humans, and to develop and refine better surrogates for exposure of the cohort and verify surrogates of exposure are accurate by monitoring a cohort subset.

Develop animal models for susceptible human populations. Unlike many other air pollutants the EPA has studied in the past that primarily target the respiratory system, PM exposure has also been found to cause significant changes in the cardiac and circulatory systems. There are currently very few animal models of human cardiovascular disease that can be applied to PM. In order to fully understand why certain diseases render an individual more susceptible to PM, better animal models must be developed, particularly those that use cutting-edge transgenic technology to target specific disease processes.

Determine the interaction of PM with gaseous co-pollutants. One of the ten priority areas identified by the NRC was to understand the interactions between PM and other air pollutants, relative to health effects. Current toxicological research is focused primarily on characterizing the effects of specific PM components in an effort to identify the fraction(s) of ambient PM responsible for adverse health effects. Given resource constraints, research on effects of simultaneous exposures to PM and gaseous co-pollutants will progress at a limited rate.

Improved Communications of Technical Information and Tools

Communicating the results of ORD's PM research is critical to the long-term utility of the work. Depending upon the topic, the most effective communication venues may be scientific symposia, conferences, and journals, particularly if the primary audience of interest is the scientific community. In other cases, however, more in-depth technology transfer is needed. This is particularly true for implementation-related efforts whose end users are usually regulatory agencies at the Regional, state, tribal, and local levels, or technical experts in the regulated community. In these instances, there is a need for channels of more focused communication, including meetings with state and local agencies and experts, workshops on emission measurements, air quality and receptor modeling, and monitoring. In addition, effective communication would also include a dedicated contact person in a particular area that would provide support for the external outreach efforts noted above as well as for hotline-type activities that external customers could contact in between the technical meetings.

APPENDIX A
Details of Cross-Program Links

Ozone

Improvements to air quality models and to emission models and inventories for PM will benefit ozone prediction efforts by improving the accuracy of model inputs and the modeling of atmospheric reactions of organic compounds. Many of the modeling issues (emission inventories, atmospheric chemistry, processing speed, etc.) for PM and ozone are the same, resulting in benefits to both programs. Studies of the health effects associated with PM copollutants will include ozone, which will improve our understanding of how the presence of ozone in the ambient atmosphere impacts public health. Currently planned human exposure studies are focusing on both PM and Air Toxics. The studies will also include a source-based component to identify potential sources of PM and Air Toxics and how these sources impact human exposures.

Air Toxics

The increased emphasis on carbonaceous particles in the PM program will provide additional information on emissions of organic and inorganic HAPs as inventories are improved and as source apportionment models are applied to better understand carbonaceous PM sources. In particular, studies of open burning and mobile source emissions will increase our understanding of HAP sources and their contribution to ambient concentrations.

Climate Change

PM research to better quantify and understand emissions of elemental carbon has important implications for climate change. "Black carbon," which is in many (but not all) cases the same as elemental carbon, has been suggested in several studies as increasing the rate of climate change. Efforts to improve measurement and inventories of elemental carbon will provide important information to climate change researchers who are evaluating the impacts of black carbon. Alternatively, organic carbon is thought to decrease the rate of climate change, as are sulfate particles, and efforts to reduce these pollutants will also impact estimates of climate change.

Mercury

Evaluations of how changes in control technologies, particularly the use of selective catalytic reduction (SCR), can lead to increased emissions of acid aerosols (H2SO4) and sulfur trioxide (SO3) that can often form visible plumes are also important to understanding how these technologies may impact mercury speciation. SCRs are thought to affect mercury speciation and capture potential, so research on control technologies to reduce PM can impact mercury capture, and vice versa.

APPENDIX B: Long Term Goals and Associated Annual Performance Goals and Annual Peformance Measures

Note: Resource levels are not reflected in the APMs or APGs, and there is significant variation between the expected resources allocated to APMs and APGs. Thus, an APG with few APMs may have as much or more funding associated with it as an APG having many APMs. Funding levels may also fluctuate for a specific APG or APM over the course of several years, depending upon the needs of the research at a given time.

APGs and APMs: PM 2.5 Implementation LTG

PERFORMANCE GOALS AND MEASURES		YEAR	LAB/ CENTER	Classification
LTG - By 2006, develop and transfer new data and tools needed by OAR and the states to predict, measure, and reduce ambient PM and PM emissions to attain the existing PM NAAQS.		**2006**	**ORD**	**N/A**
2003 APG - Deliver tools and methods to regulators that help determine sources of PM measured at ambient monitors; improve emission estimates for ammonia and directly emitted PM; improve ambient PM measurements; evaluate air quality models; assess control options to improve PM NAAQS implementation plans.		**2003**	**ORD**	**Internal**
APM	Prepare a report evaluating a new PM control technology, electrostatic fabric filtration, for use on coal-fired boilers.	2003	NRMRL	Key
APM	To support the OAR PM regulatory program, produce a paper on emissions of ammonia from hog waste lagoons, both before and after application of mitigation techniques.	2003	NRMRL	Key
APM	Complete analysis of organic compounds in PM samples from combustion sources. Data will be used to update an OAR database used by states to determine sources of ambient PM.	2003	NRMRL	Key
APM	Complete a summary paper characterizing fugitive fine particle emissions from construction activities.	2003	NRMRL	Reporting

APG - Provide improved information on emissions of fine particles to support analyses of implementation strategies.		**2004**	**NRMRL**	**Internal**
APM	Develop improved emission factors for heavy duty diesel trucks	2004	NRMRL	Internal
APM	Provide data on improved control technologies including electrostatically enhanced fabric filters and other hybrid PM collection technologies	2004	NRMRL	Internal
APG - Deliver improved receptor-oriented models and new data on chemical compounds emitted from sources to OAR and states to improve their ability to identify types of sources that contribute to the mass of particulate matter (PM) in the ambient air so that more effective PM emission control strategies can be developed to achieve attainment of the PM NAAQS.		**2005**	**NERL/ NRMRL**	**External**
APM	Deliver to OAR and the States an alternative, easy-to-use receptor model that identifies the relative source contributions for PM pollution needed to develop effectively targeted control strategies.	2004	NERL	Internal
APM	Deliver to OAR and the states a receptor-oriented modeling tool that identifies important source regions and quantifies relative source contributions for PM that can be used to more effectively target source control strategies.	2005	NERL	External
APM	Report on speciated organics source profiles from gasoline-fueled motor vehicles, for use in source apportionment of ambient samples.	2005	NERL	Internal
APM	Develop and transfer to OAR and the states improved PM2.5 compositional profiles for emissions from three major pulp and paper mill processes.	2003	NRMRL	Internal

APM	Provide detailed information on chemical species emitted from oil burners and furnaces and transfer these findings through reports and journal articles to OAR and the states so they can utilize them in models that identify which sources are contributing to measured concentrations of PM in ambient air.	2005	NRMRL	External
APM	Develop and transfer to OAR improved PM emission factors and compositional profiles for commercial jet aircraft engines.	2005	NRMRL	Internal
APG - Deliver to OAR and states an updated air quality model with improved atmospheric chemistry and processing speed, and improved data on emissions and ambient concentrations used as inputs to the model, for use in preparation and evaluation of SIP development, application, and compliance determination.		**2006**	**NERL/ NRMRL**	**Internal**
APM	Test CMAQ model predictions against a year's trace gas and PM measurements from the speciation network and Supersites to build confidence in the CMAQ's use by States in their PM NAAQs implementation.	2004	NERL	Internal
APM	Evaluate Models-3/CMAQ for particulate matter using episodic data.	2004	NERL	Internal
APM	Provide a PM chemistry model for incorporation into SIP modeling that includes the key chemical reactions that control the concentrations of organic and inorganic compounds in PM.	2004	NERL	Internal
APM	Deliver to OAR and States an updated CMAQ release for SIP development with improve performance in predicting nitrates and organics and increased processing speed.	2005	NERL	Internal
APM	Provide measurements of the estimated biogenic emissions contribution to ambient PM which can be used to develop more effective implementation strategies for reducing ambient PM levels.	2005	NERL	Internal

APM	Deliver to OAR, States, and the scientific community data from the Supersites program via an internet accessible large relational database that can be utilized for air quality model evaluation and to perform integrated analyses of data from the various Supersite locations.	2005	NERL	Internal
APM	Transfer to OAR and the states scientific information describing how ammonia sinks influence the level of emitted ammonia that is transferred to the well mixed atmosphere.	2005	NRMRL	Internal
APM	Deliver to OAR and the States results from the Supersites program that can be used to prepare and evaluate SIPs.	2006	NERL	Internal
APM	Develop and transfer to OAR and the states data on emissions of ammonia from cattle and poultry raising operations.	2006	NRMRL	Internal
APG - Transfer to OAR and the states information on the performance, cost effectiveness, and applicability of control technologies for PM and PM precursors		**2006**	**NRMRL**	**Internal**
APM	Transfer to OAR technical information to guide the development of SO2 and NOx control technology requirements for coal-fired boilers, to prevent formation of visible acid aerosol plumes.	2005	NRMRL	Internal
APM	Report on cost and performance of combined PM/PM precursor pollution control systems.	2006	NRMRL	Internal

APGs and APMs: PM Short Term Exposures LTG

LTG - By 2009, develop and transfer to ORD and OAR new exposure, epidemiological, toxicological, and clinical data for improved assessments of health risks associated with short-term exposure to PM, especially in susceptible populations.		**2009**	**NHEERL/ NERL/ NCER/ NRMRL**	**N/A**
APG - Describe health effects of PM and its components in normal and susceptible populations, mechanisms by which PM exerts adverse health effects, and analyze ambient and personal exposure to PM for submission to ORD and OAR in support of future PM Air Quality Criteria Documents and NAAQS development		**2003**	**NHEERL/ NCER**	**Internal**
APM	Describe the relative importance of PM attributes (physical, chemical, and biological) on health outcomes in laboratory animals and humans.	2003	NHEERL	Internal
APM	Ascertain attributes of susceptibility contributing to the responsiveness of cardiovascular- and pulmonary- compromised humans and laboratory animals.	2003	NHEERL	Internal
APM	Report on the acute respiratory health effects of particulate matter and co-pollutants among asthmatic children in seven U.S. communities (ICAS).	2003	NHEERL	Internal
APM	Report on the chronic respiratory health effects in children of intra-urban gradients of particulate matter and co- pollutants in El Paso, TX.	2003	NHEERL	Internal
APM	Publish report on the empirical and theoretical lung deposition dose of ultrafine, fine, and coarse particles in elderly and mild asthmatic subjects under various breathing conditions.	2003	NHEERL	Internal
APM	Report on the cardiovascular health effects associated with combined exposure to PM and gaseous co-pollutants.	2003	NCER	Internal

APM	Report on the respiratory health effects associated with ultrafine, fine and coarse particles in laboratory animals.	2003	NCER	Internal
APM	Report on the association between organic components of PM and health endpoints in susceptible subpopulations.	2003	NCER	Internal
APM	Report on ambient exposure to PM size fractions and components, and biomarkers of exposure.	2003	NCER	Internal
APG - Provide reports to OAR and the scientific community that examine the health effects of high levels of air pollutants, especially particulate matter, in potentially susceptible populations so that future PM standards protect human health to the maximum extent possible.		**2004**	**NHEERL**	**Internal**
APM	Report on epidemiologic studies examining acute cardiac and respiratory effects in the elderly and children exposed to PM and co-pollutants.	2004	NHEERL	Internal
APM	Report on the chronic respiratory health effects in children of intra-urban gradients of particulate matter and copollutants in EL Paso, TX .	2004	NHEERL	Internal
APG - Identify toxic source based components to be assessed for dose response studies		**2004**	**NHEERL**	**Internal**
APM	Report on the role of source attributed PM constituents in mediating cardiopulmonary injury in healthy humans and animal models.	2004	NHEERL	Internal
APM	Determine the relative toxicity of PM derived from various combustion sources (oil, coal etc.).	2004	NHEERL	Internal
APG - Describe health effects of different PM sizes in healthy animals and humans		**2005**	**NHEERL/ NCER**	**Internal**
APM	Distinguish the respective toxic potentials of model and ambient PM size fractions in healthy animals and humans.	2005	NHEERL	Internal

APM	Describe mechanisms by which different size fractions mediate pulmonary injury, using a model in vitro culture system.	2005	NHEERL	Internal
APM	Report on the respiratory health effects associated with concentrated airborne particles from Fresno in healthy rats.	2004	NCER	Internal
APG - Identify factors of susceptibility for acute PM exposures in susceptible subgroups		**2006**	**NHEERL/ NCER**	**Internal**
APM	Report on the deposition and effects of fine and ultrafine PM in compromised animal models.	2004	NCER	Internal
APM	Describe respiratory deposition dose of ambient particles in moderate asthmatic and COPD patients.	2004	NHEERL	Internal
APM	Report on development of a better rat model of human chronic obstructive pulmonary disease, demonstrate its utility in PM health effects studies.	2004	NHEERL	Internal
APM	Relate the effects of exposure to various PM and PM surrogates on cardiopulmonary function and inflammation in a susceptible animal model.	2004	NHEERL	Internal
APM	Describe cardiopulmonary effects of ambient PM on select susceptible populations.	2005	NHEERL	Internal
APM	Report on factors (e.g., diabetes) that may predispose to increased risk of hospital admissions associated with PM exposure.	2005	NCER	Internal
APM	Report on the relationship of exposure to ambient PM and heart rate variability in two epidemiology studies.	2005	NCER	Internal
APM	Report on cardiopulmonary responses to fine and ultrafine particles in clinical studies of healthy subjects and two sensitive subgroups.	2005	NCER	Internal
APM	Determine whether cigarette smokers are a sensitive population with respect to diesel exhaust.	2006	NHEERL	Internal

APM	Describe biological mechanisms by which inhaled concentrated particles affect cardiopulmonary endpoints in at least two animal models of disease.	2006	NCER	Internal
APM	Comprehensive assessment of health effects of ultrafine particles.	2006	NCER	Internal
APG - Determine the critical factors influencing exposure to PM constituents with potential for short-term health effects using measurement data and exposure modeling for the general and susceptible populations.		**2006**	**NERL/ NCER**	**Internal**
APM	Provide an analysis of key factors influencing indoor concentrations of PM and describe their impact on short-term personal exposures to be used by EPA to improve PM exposure assessments.	2004	NERL	Internal
APM	Develop a probabilistic exposure and dose model for PM capable of predicting population exposures to selected PM constituents that may be responsible for observed health effects so that EPA can produce improved exposure and risk assessments for short-term exposure to PM.	2004	NERL	Internal
APM	Analyze existing data on PM composition to identify key factors which influence human exposures to PM constituents.	2005	NERL	Internal
APM	Develop models of exposure that characterize Northwest aerosols and assess contributions from different sources.	2005	NCER	Internal
APM	Identify the critical physical, microenvironmental and other exposure factor data needs for assessing short-term exposure to PM constituents using a probabilistic exposure and dose model.	2006	NERL	Internal
APG - Characterize combined effects of PM and gaseous co-pollutants on healthy animals and humans		**2008**	**NHEERL/ NCER**	**Internal**

APM	Describe cardiopulmonary effects of PM and gaseous co-pollutants in healthy humans.	2005	NHEERL	Internal
APM	Evaluate an animal and in vitro bioassay for assessing the relative potency of surrogate PM and/or its components.	2005	NHEERL	Internal
APM	Describe cardiopulmonary effects of diesel exhaust particles in healthy humans.	2006	NHEERL	Internal
APM	Provide three examples of coherent biological responses between animal toxicology and human population studies.	2007	NHEERL	Internal
APG - Identify and link effects and mechanisms of toxicity for PM constituents/sources		**2008**	**NHEERL/ NCER/ NRMRL**	**Internal**
APM	Assess oxidative effects of PM metals and peroxides in the lung.	2004	NHEERL	Internal
APM	Report on biological mechanisms activated by diesel exhaust particulate in a mouse asthma model and in *in vitro* studies.	2004	NCER	Internal
APM	Characterize the effects of ambient PM and/or its components on cardiac cells.	2005	NHEERL	Internal
APM	Report on organic chemical constituents of PM, including PAHs and quinones, and determination of molecular mechanisms of toxicity.	2005	NHEERL	Internal
APM	Prepare a report demonstrating that the biological effect of PM is dependent on a mobilization of host metal with a resulting elevation in catalytically active metal and oxidative stress.	2005	NHEERL	Internal
APM	Describe the signal transduction pathways through which PM causes inflammation in pulmonary epithelial cells.	2005	NHEERL	Internal
APM	Application of a molecular profiling approach to ascertaining cardiopulmonary effects in healthy animal models after model and ambient PM exposures.	2005	NHEERL	Internal

APM	Describe a molecular profiling approach to characterize cardiopulmonary effects in humans and cultured cells exposed to PM.	2006	NHEERL	Internal
APM	Link health effects in humans exposed to PM with specific sources of pollution.	2006	NHEERL	Internal
APM	Provide a detailed model describing the molecular events which control PM-induced pulmonary effects.	2007	NHEERL	Internal
APM	Use high resolution computer simulations to target the dose to various sites in human lungs, linking to local tissue burden of and cellular response to PM.	2007	NHEERL	Internal
APM	Examine responses of healthy adults to CAPs and traffic-related particulate to assess mechanisms of cardiovascular health effects.	2007	NCER	Internal
APM	Develop data on the size distribution and detailed chemical composition of fresh and aged combustion-generated particles produced from full- and pilot-scale systems for use in real time inhalation toxicology studies.	2008	NRMRL	Internal
APG - Generate new data and analyses to characterize exposure and exposure factors for the general and susceptible subpopulations for PM constituents and co-pollutants from various sources with potential for short-term health effects using exposure measurements and modeling.		**2009**	**NERL**	**Internal**
APM	Complete field data collection for field studies to assess ambient, indoor, outdoor, and personal exposure to PM constituents and co-pollutants with potential for short-term health effects and compile a database of toxic agent concentrations, exposures, participant activities, and exposure factors to be used for model input and evaluation.	2007	NERL	Internal

APM	Report on personal exposures and indoor air concentrations for PM constituents and co-pollutants with potential for short-term health effects for the general population and sensitive subpopulations.	2008	NERL	Internal
APM	Report on the magnitude and variability of the relationships between personal exposure, and indoor, outdoor and ambient air concentrations and factors that contribute to the variability for PM constituents and co-pollutants with potential for short-term health effects for the general population and sensitive subpopulations.	2009	NERL	Internal
APM	Report on the influence of various sources on exposure to PM constituents and co-pollutants by applying source apportionment techniques to personal and indoor air PM data.	2009	NERL	Internal
APG - Produce a refined and evaluated exposure model for predicting population distributions of exposure and dose for PM constituents and co-pollutants from various sources with potential for short-term health effects.		**2009**	**NERL**	**Internal**
APM	Refine population exposure model for PM constituents and co-pollutants using available data and improved algorithms, and apply refined model in a case-study to predict exposures for the general population and susceptible subpopulations to PM constituents and co-pollutants.	2007	NERL	Internal
APM	Evaluate population exposure model against new exposure data on PM constituents and co-pollutants from NERL or other measurement studies.	2008	NERL	Internal
APM	Incorporate source apportionment in model prediction of population exposure and dose for PM constituents and co-pollutants.	2009	NERL	Internal

APGs and APMs: Air Quality Criteria Document LTG

LTG - By 2010, integrate and assess new findings in atmospheric, exposure, biological, and engineering sciences and regularly communicate the state of science to OAR to improve environmental decision-making for the PM NAAQS.		**2010**	**NCEA/ NHEERL/ NERL/ NRMRL/ NCER**	**N/A**
APG - Identify and communicate research needs and develop research strategies and plans to improve scientific information supporting the next review of the NAAQS		**2006**	**NCEA/ NHEERL/ NERL/ NRMRL/ NCER**	**External**
APM	Research Needs Document published.	2005	NCEA	External
APM	PM Research Strategy/Plan(s) developed and reviewed by CASAC.	2006	NCEA/ NHEERL/ NERL/ NRMRL/ NCER	External
APG - Integrate research to assess scientific bases for the PM NAAQS and strengthen the scientific foundation for EPA PM NAAQS regulatory decisions		**2008**	**NCEA**	**External**
APM	PM AQCD Development Plan released for public comment and CASAC review.	2006	NCEA	External
APM	External Review Draft of the PM AQCD released for public comment and CASAC review.	2007	NCEA	External
APM	Final PM AQCD published and delivered to OAQPS.	2008	NCEA	External
APG - Provide scientific and technical guidance and analyses to ensure strong scientific bases for regulatory decisions during the 2010 PM NAAQS rulemaking (staff paper, proposal and promulgation) process.		**2010**	**NCEA**	**Internal**
APM	Synthesis Report on ORD's scientific contributions to the 2010 PM NAAQS Promulgation issued.	2010	NCEA	Internal

APGs and APMs: Post Sulfur Implementation Needs LTG

LTG - By 2012, develop and transfer improved data and tools needed by OAR and the states to attain existing PM NAAQS, and by ORD and other scientists to refine the environmental factors related to health risks associated with PM exposure.		**2010**	**NERL/ NRMRL/ NCER**	**N/A**
APG - Update and enhance tools used to model, measure, and reduce mass to improve implementation of mass based standards.		**2010**	**NERL/ NRMRL/ NCER**	**Internal**
APM	Deliver to OAR a Federal Reference Method (FRM) to measure coarse particles for inclusion in the revised PM NAAQS.	2005	NERL	Internal
APM	Evaluation of continuous methods for composition and physical properties based on results from the Supersites programs.	2006	NERL	Internal
APM	Develop an Air Quality Forecasting model for particulate matter and visibility for use in short-term forecasts.	2007	NERL	Internal
APM	Deliver to OAR and the States an updated air quality model that includes coupled meteorology and air chemistry modules.	2008	NERL	Internal
APM	Evaluate the use of human exposure models to enhance implementation of PM NAAQS.	2008	NERL	Internal
APM	Develop and transfer data on the use of techniques to improve the cost effectiveness of reducing sulfur in transportation fuels.	2008	NRMRL	Internal
APM	Develop continuous methods for PM mass, chemical components, and major precursor species with improved accuracy and precision, fewer impacts from interferences, and with improved time resolution.	2010	NCER	Internal
APM	Provide techniques for modeling the intercontinental transport of particulate matter and precursors and their impact on U.S. ambient air quality.	2010	NERL	Internal

APM	Develop and transfer to OAR, the states, and regulated industries data on the performance of cost-effective pollution control technologies to reduce multiple pollutants, including PM and PM precursors.	2010	NRMRL	Internal
APG - Produce data and tools to better predict and measure relationships between sources and fate of carbonaceous particles to address potential residual non-attainment issues.		**2009**	**NERL/ NRMRL NCER**	**Internal**
APM	Transfer to OAR and the States standards and improved methods for measuring the organic carbon and elemental carbon fractions of PM.	2005	NERL	Internal
APM	Report on the characterization of PAHs from two Los Angeles locations and assess atmospheric chemistry occurring during different seasons	2005	NCER	Internal
APM	Provide to OAR and the States standards and improved methods for organic speciation of fine particles.	2006	NERL	Internal
APM	Develop and transfer to OAR and the states test methods and equipment designs for determining PM emissions from off-road diesel construction equipment.	2006	NRMRL	Internal
APM	Develop and transfer to OAR and the states improved emission factors for diesel-electric railroad locomotives.	2007	NRMRL	Internal
APM	Evaluation of molecular organic tracers for use in receptor models.	2008	NERL	Internal
APM	Develop and transfer data on emissions factors from off-road diesel construction equipment.	2008	NRMRL	Internal
APM	Transfer information to OAR and the states regarding emission rate and characteristics for open burning of biomass in wild and prescribed fires.	2008	NRMRL	Internal

APM	Transfer to OAR and the states methods for temporal and spatial allocation of emissions from on-road diesel truck activity for GIS-based modal emission models	2008	NRMRL	Internal
APM	Transfer data to OAR and the states on the chemical characterization of carbonaceous PM as a function of particle size.	2008	NRMRL	Internal
APM	Transfer to OAR and the states fluorescence intensity methods for characterizing the composition of carbonaceous particles.	2008	NRMRL	Internal
APM	Develop and evaluate better methods for measuring a greater number of organic species in PM2.5, including polar organic compounds and semi-volatile organic species.	2008	NCER	Internal
APM	Identify and quantify new, organic, aerosol tracers in ambient samples for important PM2.5 sources.	2008	NCER	Internal
APM	Improve simulation of the chemical and physical transformation and transport of carbonaceous PM2.5 and improve fundamental processes for understanding air quality model development.	2008	NCER	Internal
APM	Measure and speciate carbonaceous PM2.5 for major combustion source categories including fossil fuel, agricultural burning, and wildfires.	2008	NCER	Internal
APG - Transfer to OAR and the states data and tools to predict and measure how changes in emissions of PM and PM precursors due to control strategies impact the atmospheric formation and transport of PM to improve the effectiveness of control strategies to address residual nonattainment.		**2010**	**NERL/ NRMRL/ NCER**	**Internal**
APM	Report on the composition of ultrafine particles from a variety of sources and assess the utility of these data for source attribution.	2005	NCER	Internal

APM	Develop a first generation chemistry module that can be used to predict the concentrations of free radicals, liquid water, inorganics including transition metals, and organics in ambient PM2.5 samples.	2006	NERL	Internal
APM	Deliver to OAR and the states an evaluation and recommendations for using various receptor modeling techniques based upon model applications using data from the Speciation Trends Network and the Supersites program.	2007	NERL	Internal
APM	Develop and transfer to OAR and the states data on alternate animal waste disposal systems and their impacts on emissions and on local deposition of nitrogen to surrounding soils and water bodies.	2007	NRMRL	Internal
APM	Complete evaluation of a chemistry module that can be used by EPA and the states to predict the concentrations of free radicals, liquid water, organics and inorganics in ambient PM2.5 samples.	2008	NERL	Internal
APM	Develop and transfer to OAR and the states the ability to identify and quantify fugitive source particle emissions using open path FTIR spectroscopy.	2008	NRMRL	Internal
APM	Improve estimates of the sources of PM2.5 and the regional variations in the importance of sources; and evaluate potential emission control strategies to examine effectiveness and potential trade-offs.	2009	NCER	Internal
APM	Develop and transfer to OAR and the states data on how long range transport of PM generated by wild and prescribed fires impacts local air quality.	2010	NRMRL	Internal
APM	Develop and transfer to OAR and the states data on the unresolved organic fraction of carbonaceous PM emissions.	2010	NRMRL	Internal

APGs and APMs: PM Long Term Exposures LTG

LTG - By 2014, develop and transfer to ORD and OAR new exposure, epidemiological, toxicological, and clinical data for improved assessments of health risks associated with long-term exposure to PM, especially in susceptible populations.		**2014**	**NHEERL/ NERL/ NCER**	**Internal**
APG - Determine critical factors (methods, measurements, models) for assessing exposure in health studies of long-term exposure to PM, PM constituents and co-pollutants.		2004	NERL	Internal
	Document the data and calculations needed to predict the long-term exposures to PM and its constituents so that EPA can better assess risks for long-term exposures to PM.	2004	NERL	Internal
APG - Characterize long term cardiopulmonary effects of PM and co-pollutants based on existing cohorts		**2008**	**NCER**	**Internal**
APM	Report on the relationship between respiratory outcomes in the Children's Health Study in California, and 1) traffic density and 2)specific PM sub-components including PAH, quinones, VOCs, semi-VOCs.	2004	NCER	Internal
APM	Report on the health effects of long-term exposure to particles and co-pollutants in at least two cohorts.	2005	NCER	Internal
APM	Assess cardiovascular and other effects of long-term exposures to PM in at least three cohorts, applying improved methods of exposure assessment.	2007	NCER	Internal
APG - Characterize long term respiratory health effects of PM in children.		**2009**	**NHEERL/ NCER**	**Internal**
APM	An innovative protocol for incorporating testing for allergen sensitization among a selected subsample of schoolchildren.	2005	NHEERL	Internal
APM	A revised children's respiratory health questionnaire approved by OMB.	2006	NHEERL	Internal

APM	Report on effects of particle composition on respiratory health of children.	2006	NCER	Internal
APM	Complete survey of the respiratory symptoms and pulmonary function among 4th and 5th grade school-children in second major urban area.	2007	NHEERL	Internal
APM	Peer-reviewed scientific publication on the chronic respiratory health effects in children of intra-urban gradients of particulate matter and co-pollutants in a second major urban area.	2009	NHEERL	Internal
APG - Strengthen health studies of long-term exposure by developing accurate surrogates of long-term exposure and describing exposure misclassification errors that may influence estimates of health risks for PM constituents and co-pollutants.		**2010**	**NERL**	**Internal**
APM	Document current data gaps and initiate targeted studies to quantify critical factors for exposure in health studies of long-term exposure to PM, PM constituents and co-pollutants.	2005	NERL	Internal
APM	Produce data and analyses that fill data gaps on critical factors for exposure in health studies of long-term exposure to PM, PM constituents and co-pollutants.	2008	NERL	Internal
APM	Apply, evaluate and refine human exposure models for predicting long-term exposure to PM, PM constituents and co-pollutants.	2009	NERL	Internal
APM	Using measurement and modeling results identify surrogates for exposure for predicting long-term exposures to PM, PM constituents and co-pollutants.	2010	NERL	Internal
APG - Assess the exposure-response relationship of short-term exposures to PM and source-based components in healthy and susceptible animals and humans.		**2010**	**NHEERL/ NCER**	**Internal**

APM	Assess exposure-response relationship of PM constituents related to adverse health effects in healthy populations.	2005	NHEERL	Internal
APM	Using newly available PM speciation monitoring data, compare the impact of different PM source types on health endpoints in at least 3 states.	2005	NCER	Internal
APM	Describe cardiopulmonary effects of ultrafine/fine PM in healthy humans.	2006	NHEERL	Internal
APM	Describe cardiopulmonary effects of coarse PM in healthy humans and asthmatics.	2006	NHEERL	Internal
APM	Compare the relative potency of ultrafine, fine, and coarse PM in healthy humans.	2006	NHEERL	Internal
APM	Describe a bioassay approach to assess source directed PM constituents in the ambient environment.	2006	NHEERL	Internal
APM	Report on the relationship between exposure to traffic-related air pollutants and measures of health or biomarkers.	2006	NCER	Internal
APM	Assess exposure-response relationships in susceptible animals and humans of PM constituents.	2007	NHEERL	Internal
APG - Characterize combined effects of short-term exposures PM and gaseous co-pollutants in susceptible subgroups		**2010**	**NHEERL/ NCER**	**Internal**
APM	Report on associations between indoor and outdoor PM levels and health endpoints of individuals with COPD and recent Mis.	2004	NCER	Internal
APM	Report on acute cardiovascular responses to PM2.5 and NO2 in patients with chronic obstructive pulmonary disease.	2004	NCER	Internal
APM	Peer-reviewed scientific publication on the effects of diesel exposures on nasal DNA adducts in asthmatics and non asthmatics.	2005	NHEERL	Internal

APM	Determine whether arsenic exposure augments diesel exhaust DNA damage.	2006	NHEERL	Internal
APM	Report on improvements in statistical methods in the analysis of data from epidemiological studies.	2006	NCER	Internal
APM	Report on relationship between PM, PM components, and co-pollutants and risk of cardiac and emergency department visits in Atlanta.	2006	NCER	Internal
APM	Peer-reviewed scientific publication on the use of alternative sentinels (Mexico City) to study chronic particulate matter exposures.	2007	NHEERL	Internal
APM	Describe differences in responsiveness to between healthy and susceptible cardiopulmonary diseased animals to various PM and associated co-pollutants.	2009	NHEERL	Internal
APM	Peer-reviewed scientific publication on field collected diesel exposure biomarkers.	2010	NHEERL	Internal
APG - Describe long term health effects of PM in animals		**2011**	**NHEERL/ NCER**	**Internal**
APM	Ascertain potential markers of cardiopulmonary and systemic effects of protracted exposures to CAPs in healthy and compromised animals.	2004	NHEERL	Internal
APM	Report on health effects of CAPs in subchronic inhalation study using normal and susceptible mice.	2006	NCER	Internal
APG - Describe the mechanisms of acute health effects and link effects to PM and PM components in susceptible subgroups.		**2011**	**NHEERL/ NCER**	**Internal**
APM	Report on the linkage between PM surrogates for dose such as lung particle burden and composition with site specific cell and tissue damage in human autopsy tissue.	2004	NHEERL	Internal

APM	Award grants received in response to solicitation on cardiovascular effects of PM exposure sponsored by EPA and partners.	2004	NCER	Internal
APM	Publish the RFA for recompeting the PM Research Centers, identifying priority areas for research, with an emphasis on linking specific sources of PM to adverse health effects	2004	NCER	Internal
APM	Award five-year grants to new PM Research Centers	2005	NCER	Internal
APM	Provide an analysis of size and composition specific respiratory dose of heterogeneous ambient aerosols in human lungs.	2005	NHEERL	Internal
APM	Develop an in vitro model of human susceptibility to PM exposure in lung cells.	2006	NHEERL	Internal
APM	Report on acute effects of PM-derived metals on pulmonary cells in two studies.	2006	NCER	Internal
APM	Describe the cardiac and pulmonary health impacts of model and ambient PM on various animal models of cardiopulmonary disease (COPD, asthma, infection).	2007	NHEERL	Internal
APM	Report on effects of PM in an animal model of atherosclerosis.	2007	NCER	Internal
APM	Use molecular profiling to identify biomarkers of exposure or effect in healthy and susceptible people.	2008	NHEERL	Internal
APM	Assess the relative sensitivity to PM of select susceptible populations focusing on those with cardiovascular disease.	2008	NHEERL	Internal
APM	Describe the potential for molecular profiling approaches for identifying and assessing susceptibility factors in animals exposed to PM.	2008	NHEERL	Internal
APM	Develop an in vitro model of human lung susceptibility to PM exposure.	2009	NHEERL	Internal

APM	Describe new markers for acute cardio-pulmonary effects in elderly adults of recent exposures to particulate matter and pollutants.	2010	NHEERL	Internal
APM	Develop an in vitro model of human cardiovascular susceptibility to PM exposure.	2011	NHEERL	Internal
APG - Describe long-term health effects of PM and co-pollutants in humans.		**2014**	**NCER**	**Internal**
APM	Award major grant for prospective observational epidemiology study of long-term exposure to ambient PM and associations with the natural history of cardiovascular disease, including indicators of sub-clinical disease, clinical disease incidence, mortality, and the assessment of physiological parameters indicative of the progression of disease.	2004	NCER	Internal
APM	Report on long-term effects of PM exposure on progression of cardiovascular disease in adults, with analysis of effect modification by various risk factors.	2011	NCER	Internal

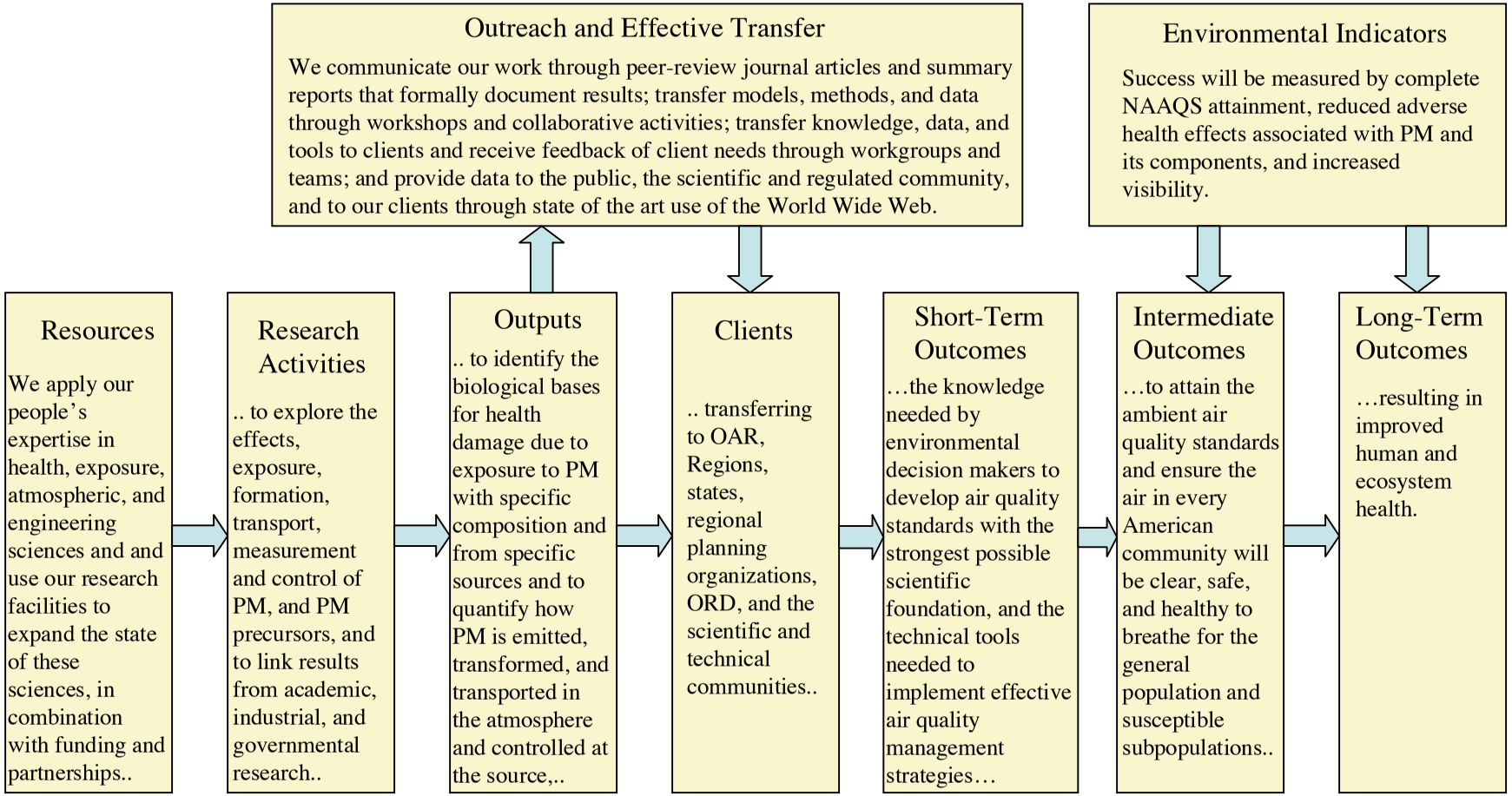

Figure 1. Logic diagram for PM research program design.

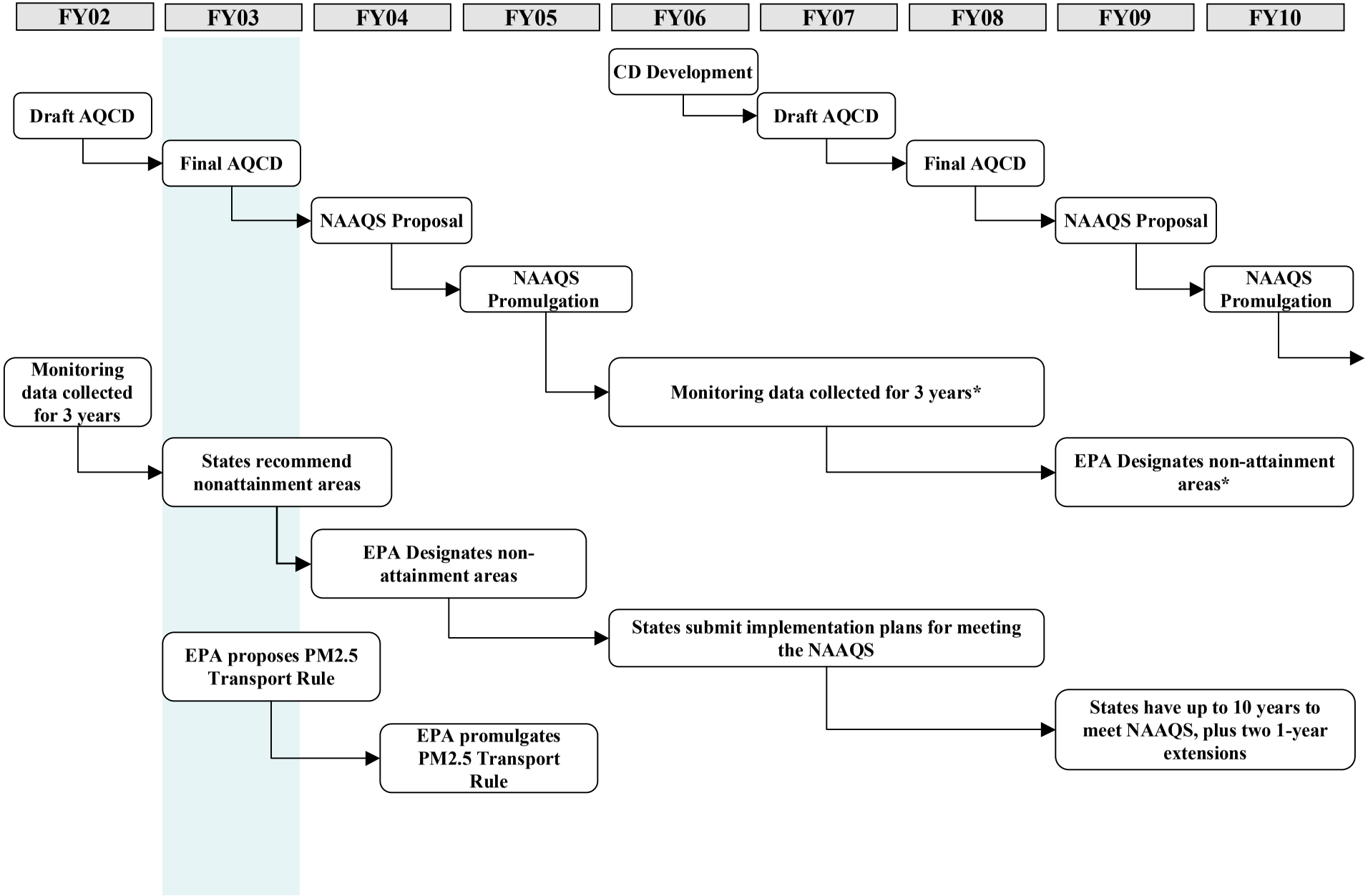

Figure 2. Anticipated regulatory time line for promulgation and implementation of NAAQS and associated regulatory programs, illustrating the cyclical nature of the program.

*If needed

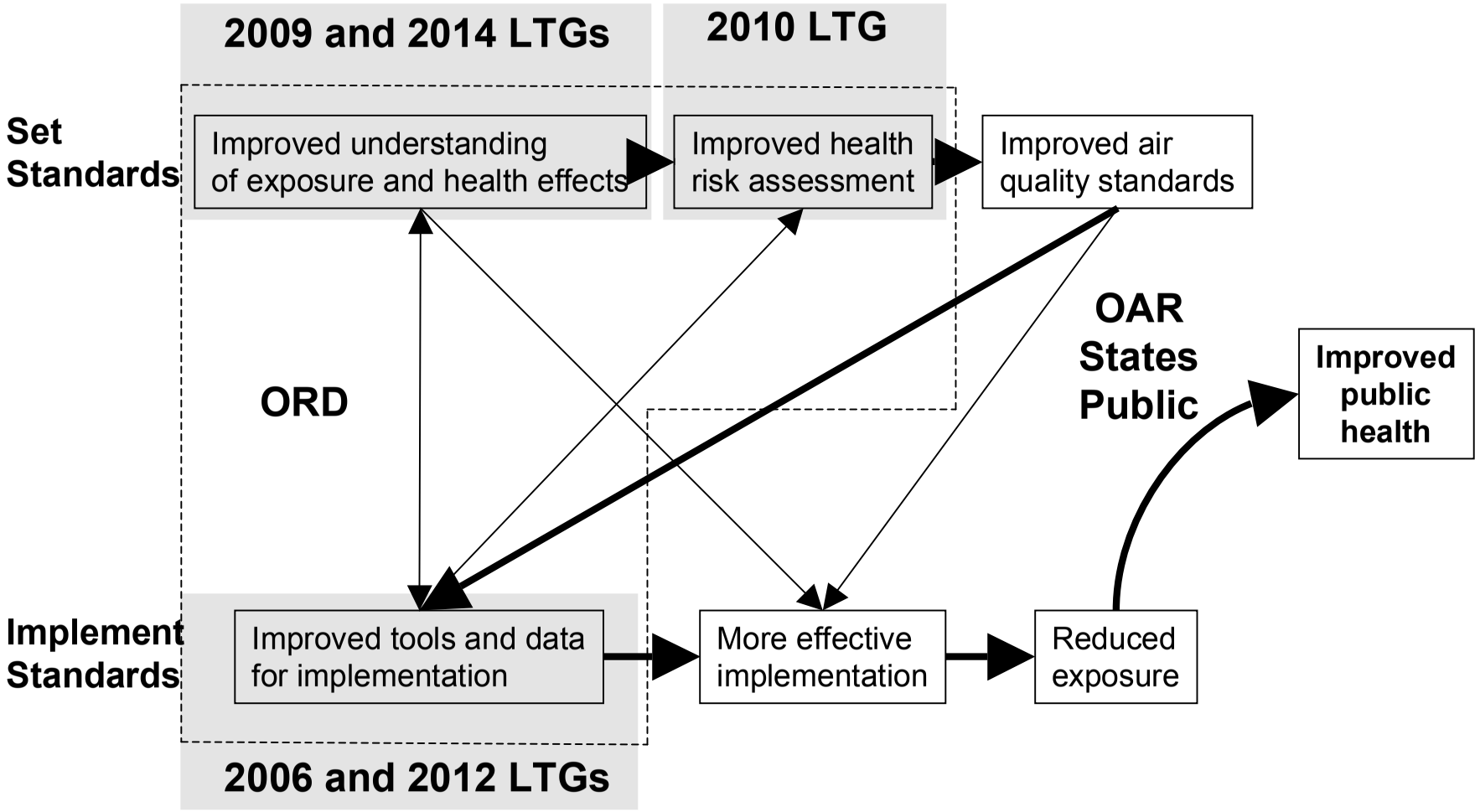

Figure 3. Relationship of LTGs to OAR and EPA outcomes. The arrows represent information flows across the key components of the research and regulatory programs. Bold arrows indicate the sequential information flow for a particular NAAQS review cycle. ORD activities occur within the dotted lines.

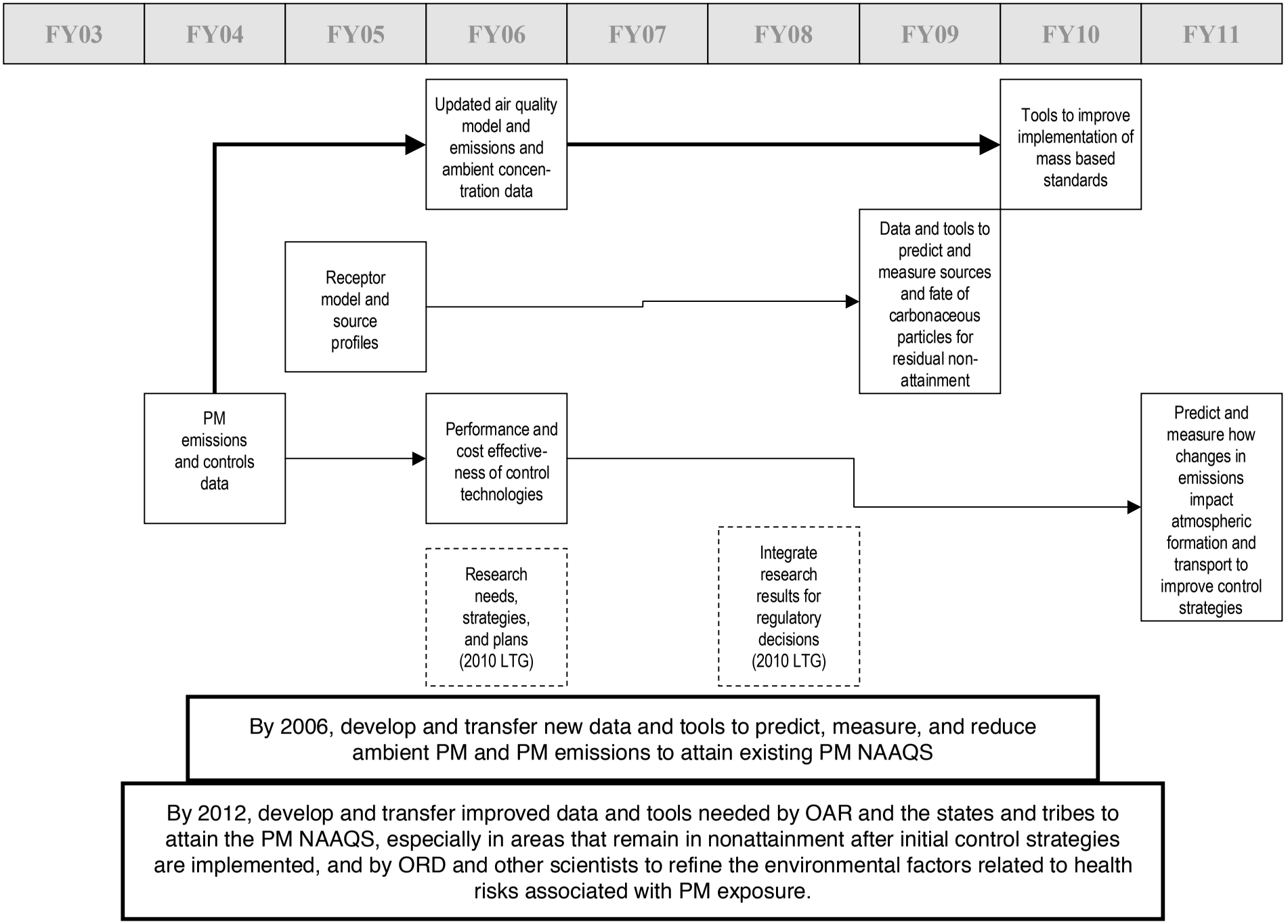

Figure 4. Implementation Research Flow Chart

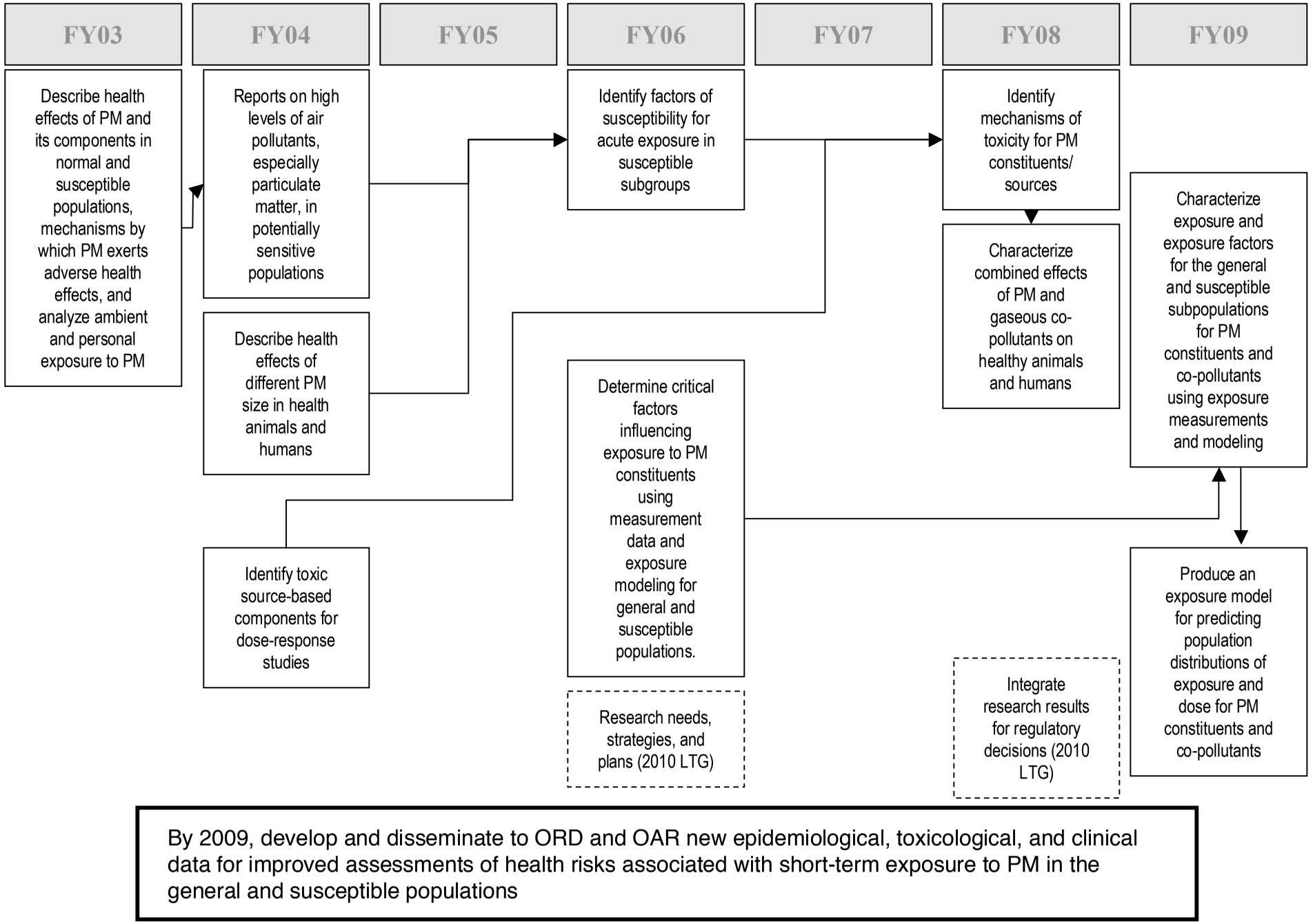

Figure 5. Health and Exposure Flow Chart for 2009 (Short-Term Exposure) LTG

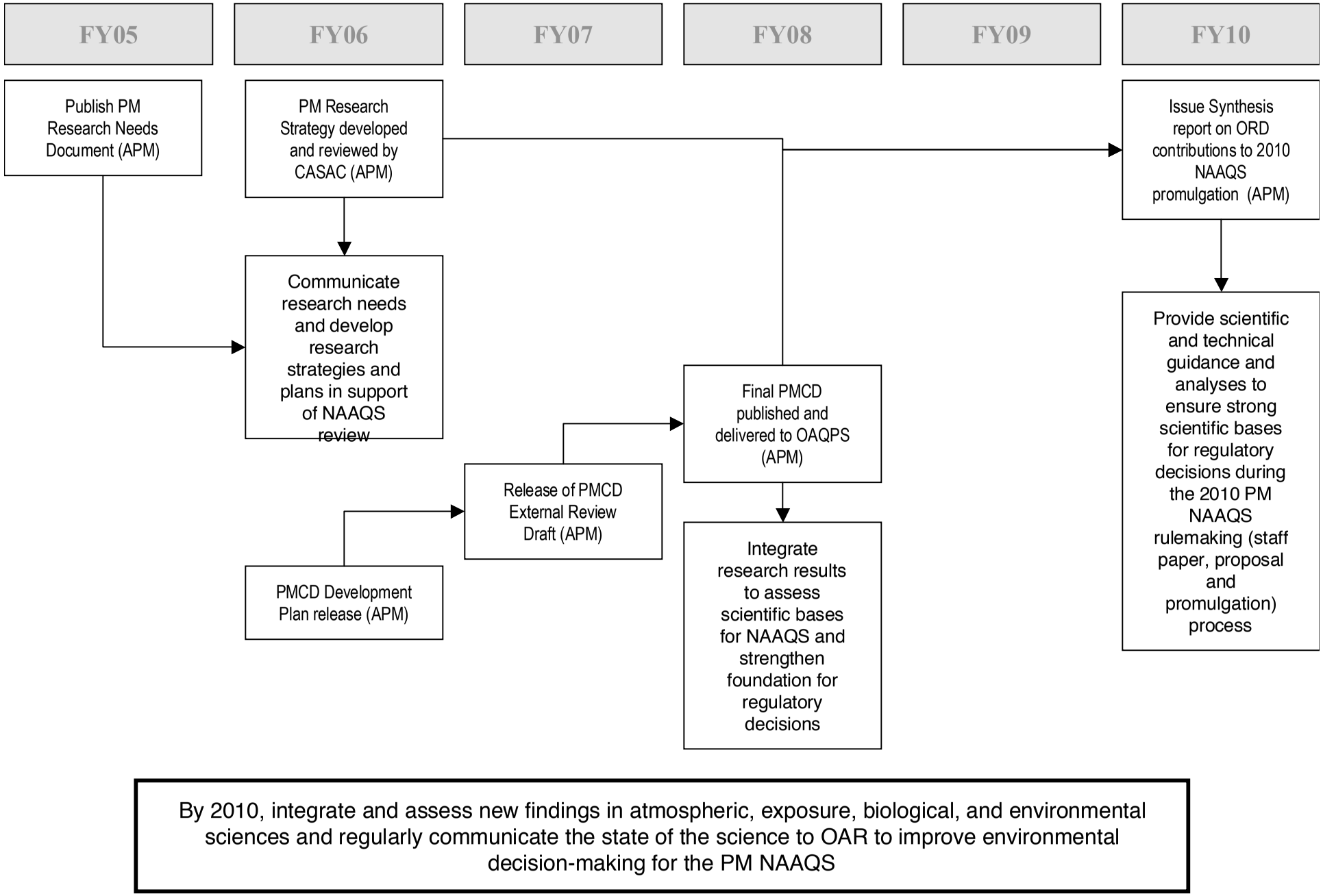

Figure 6. Flow Chart for 2010 (PM Criteria Document) LTG

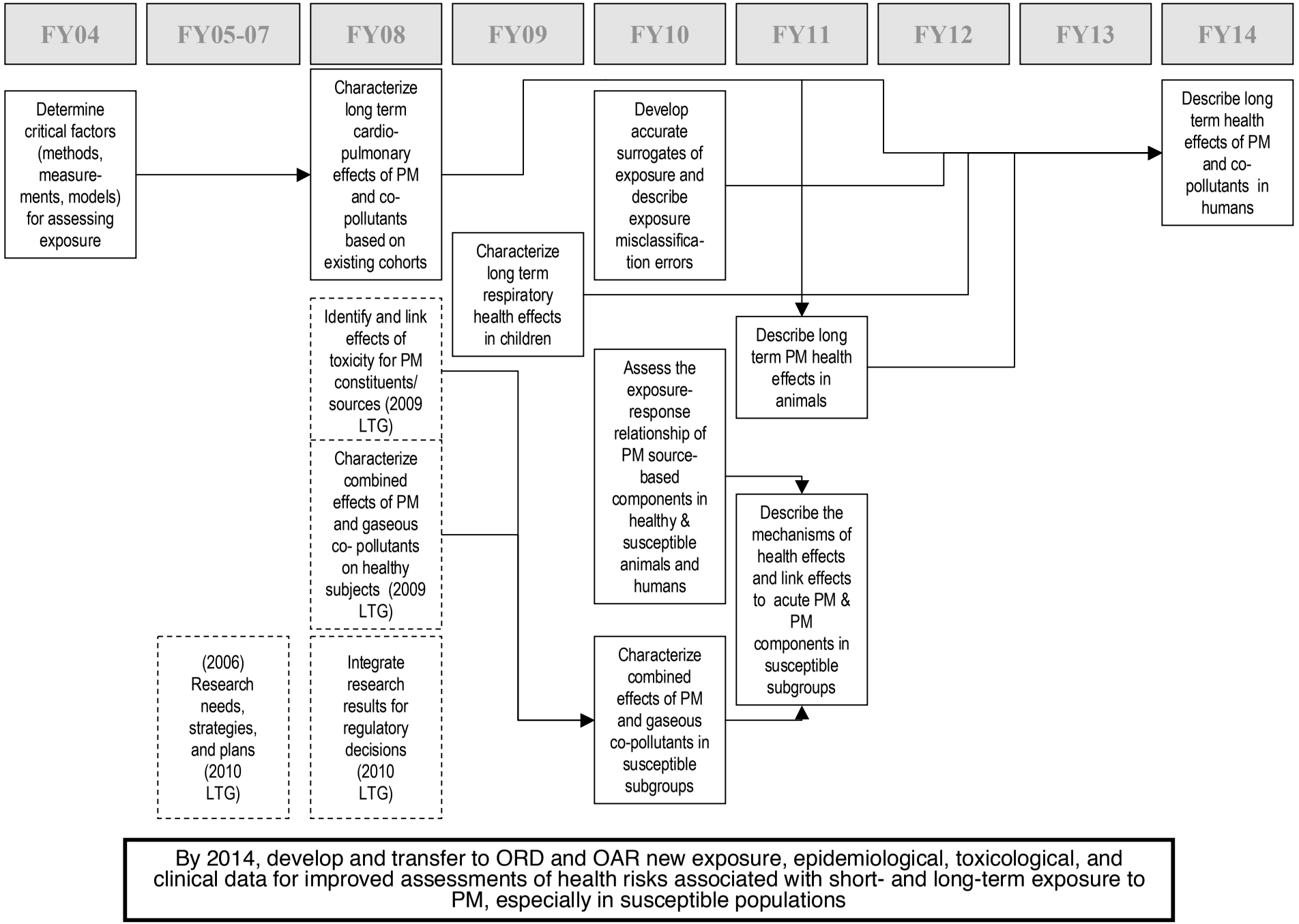

Figure 7. Health and Exposure Flow Chart for 2014 (Long-Term Exposure) LTG